Irrigation Cost Models to Assess the Feasibility and Potential Expansion of Large-Scale Riparian Irrigation in Virginia

by

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Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Agricultural Economics

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November 1991

Blacksburg, Virginia

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ACKNOWLEDGMENTS

I am indebted to Dr. Dan Taylor, my advisor and chairman on this project, for his support over the many years since I left school to start my career. His support and quiet encouragement are the reasons that allowed me to complete this project.

Thanks are owed to Dr. Blake Ross for his time, energy, and knowledge he shared with me in building the design models. My experiences and education in the irrigation field were limited to my experiences operating irrigation equipment on my family farm, and my B.S. degree in Agronomy; and I had no background in the engineering principles of irrigation. His patience with me created a very enjoyable working atmosphere and the design models are a tribute to his abilities.

Thanks are owed to my advisory committee member, Dr. Darrell Bosch, for his ability to quickly understand my work. His efforts to improve the study's quality and his assistance in this process are greatly appreciated.

Thanks are owed to Teresa Altizer for her help, encouragement, and advice. She was always there to help me. I am truly blessed to have someone who has given me such support and who has always believed in me. She is a true friend.

Thanks are owed to my father, Mr. Robert C. Lanier, and my mother, Mrs. Evelyn B. Lanier, for being my father and mother. My successes are a tribute to them and their values.

Finally, I owe much to my wife, Preciosa V. Lanier, and my son, Jon Justin Lanier. They have sacrificed for my shortcomings. I especially owe my wife for the patience she has had with me over the last six years. I love you both very much.

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CHAPTER 1

Introduction

1.1 Rationale for Study

The state of Virginia follows the Riparian Doctrine, a common law doctrine entitling each landowner adjacent to a stream the right to have water flow undiminished in quality and quantity in its natural channel. This doctrine does not give anyone the right to withdraw water from a stream, but people next to the stream can withdraw water from a stream as long as there is enough water for people downstream. Under this doctrine, each municipality and county government may have different laws governing water consumption (Turner and Anderson).

There is a trend in the state's agricultural sector to increase its use of the state's water resources through irrigation. From 1962 to 1982, irrigated acreage has increased from 32,000 to 82,000 acres, which represents an annual growth of 7.4 percent. This growth in irrigated acreage has been highly concentrated in Augusta, Rockingham, Caroline, Hanover, and King William counties (Ross, Wright, Powell, and Shanholz).

Unlike past growth in irrigation, which was directed at high cash crops like tobacco and vegetables using small portable pipe systems with water being supplied by small farm ponds, this recent growth uses large irrigation systems to irrigate field crops where the water is supplied by rivers. Relative to the cost of drilling a well and pumping

groundwater, pumping water from a river is less expensive, giving producers an economic incentive to use river water.

The Riparian Doctrine is based on plentiful water supplies and does not provide a mechanism to allocate water when supplies are scarce. In fact, the need to irrigate crops escalates when rainfall is limited and droughty conditions prevail. These same conditions cause urban homeowners to increase their use of water to irrigate their lawns.

When municipalities face short water supplies, they start controlling water use by rationing water to the more necessary day-to-day activities. When these urban homeowners pass by a farm that is operating large irrigation systems day and night, they may question why a farmer can irrigate his crops, but they can not water their lawns. As the population grows and farmers increase the number and use of large irrigation systems, the potential for clashes between these two groups could be expected to increase and water may have to be allocated either by institutional means or through an efficient market place. This potential conflict between farmer and non-farmers leads to the purpose of this study.

Before the state's water control agencies can start recommending policies that might alleviate this potential clash, there must be an objective projection as to what the future irrigation conditions may be. The focus of this thesis is to create a model that will estimate the cost of irrigating corn and can be used to assess the likelihood that field locations across Virginia will be profitable for irrigation. The objective of this thesis is thus to develop a model that will estimate the annual cost of irrigation based on

agronomic, engineering, economic, meteorological, and geographic parameters.

1.2 Economic Overview of Supplemental Irrigation

Farmers use irrigation systems to apply water in large volumes to crops. In semi-arid regions, natural rainfall falls short of crop requirements, so irrigation is necessary for crop growth. In semi-humid climates, like Virginia, natural rainfall is sufficient to sustain crop growth. However, rainfall frequencies are inconsistent and water shortages do develop throughout the growing season. Thus, irrigation systems in semi-humid climates supplement natural rainfall.

With a supplemental irrigation system, water can be managed by a producer as he manages applications of fertilizer, herbicides, insecticides and other inputs in the production process. The irrigation of field crops can be analyzed through the neoclassical paradigm, and more specifically, in the microeconomic framework of production economics as any other input in the production process is analyzed.

Each manager has a pool of resources at his disposal which he can utilize to achieve his specific objectives. One of his objectives must be to make a profit or he will be draining his resources until he reaches a point where he can no longer operate. Neoclassical theory takes this one step further and assumes the manager's objective is to maximize profits. Once the objective of maximum profits is defined, Neoclassical theory states that profits will be maximized when production is maximized given the amount of resources that are available (Gould and Ferguson).

Maximizing profits will allow producers to operate at the most efficient production level, if and only if, a farmer's risk preferences are known. Assuming a producer is risk neutral, production will be at the point where expected profits are maximized in the long run. If the producer is risk averse or risk seeking, production will be at a point lower than the point that maximizes expected profits, because the producer is willing to accept lower profits in the long run to reduce or increase his short-term risk (Anderson, Dillion, and Hardaker).

A producer facing a decision about purchasing an irrigation system could make two different decisions based on his risk preference. For example, assume that in the long run buying this system is known to reduce profits. The risk neutral producer would decide not to purchase an irrigation system, because profits are reduced. However, a risk averse producer would analyze his cash flow and see the cash flow stream is more consistent with the irrigation system than the cash flow stream is without. Even though profits are reduced, this risk averse person may feel the trade-off between lower profits, but a more consistent cash flow stream, is worthwhile; and he may purchase the irrigation system.

The mathematical modeling of risk preference functions is beyond the scope of this study. Risk preference modeling is certainly an area for future study, but a model that assumes risk neutrality is the first step. Once the risk neutral analysis is completed, this analysis could be expanded to include the impact risk reduction or production uncertainty has on the irrigation purchase decision.

1.3 Overview of Study

Many issues relating to this irrigation investment question could be studied. The objective of this thesis is very encompassing and the analysis required a pragmatic approach. In Chapter 2, the economic theory which supports the study's analysis is discussed. In Chapter 3, the logic of the irrigation design models is presented. In Chapter 4, the simulation of the design models is explained. Next, this simulated database is statistically analyzed to create econometric equations and this statistical process is explained. In Chapter 5, the irrigation cost models are interpreted and an example of their use is presented. Finally, Chapter 6 contains the summary and conclusions of this thesis with recommendations to expand the scope of this analysis by suggesting future research projects.

The econometric equations, which summarize the information produced by the design models and are explained in Chapter 4, are a useful extension of the design models, because the econometric equations can reduce the analytical time while maintaining a relatively high level of accuracy. In the next phase of this research project, these models will be used as input in determining the potential demand irrigation could place on Virginia's river systems. The econometric equations are created because the time savings more than compensates for the loss in accuracy relative to using the design models. If time is not a factor, simulating the design models will yield more accurate results.

CHAPTER 2

Economic Theory

Understanding the technical relationships and estimating these relationships in the production process are paramount in any microeconomic analysis of production. Before economic value can be placed on an input, its productivity relative to the product being produced must be known. For example, if an inch of water were added to a corn field, the expected increase in yield associated with this additional water must be known before monetary benefits can be calculated. If the monetary benefits outweigh the associated cost, the inch of water should be applied to increase profit. The relationship between inputs and their associated yield response can be summarized mathematically in a production function.

2.1 Production Functions

A production function is a mathematical formula expressing a relationship between inputs and the amount of output produced by any mix of the inputs. Since this study involves supplemental irrigation, a certain amount of production can be expected without using this input, so this study focuses on the increased yield expected when irrigation is employed. Equation 2.1 presents a mathematical representation of a production function for supplemental irrigation.

$$Y = f(X_1,X_2,X_3,X_4,X_5) \qquad (2.1)$$

where:

Y = increase in yield (bushels per acre)
X_1 = amount of irrigation water applied (inches)
X_2 = increased fertilizer applied (tons per acre)
X_3 = increased seeding (bushel per acre)
X_4 = increased labor hours (labor hours per acre)
X_5 = increased managerial input (hours per season)

2.2 Production Functions with only One Variable Input

As Equation 2.1 is written, all five inputs are varying over the production horizon. To plot this function, a six dimensional map would be required to show all the relationships. Equation 2.1 is simplified by holding all inputs at a constant level while varying one input, irrigation water applied. Equation 2.2 depicts this mathematical representation where the amount of water applied is varied while holding all other inputs constant.

$$Y = f(X_1 \mid X_2,X_3,X_4,X_5) \qquad (2.2)$$

where:

$\mid$ = "given that all other factors are held constant"

Equation 2.2 simplifies the analysis of various physical production relationships compared to Equation 2.1. Equation 2.2 focuses on the yield response expected from applying irrigation water, or input X_1, while all other factors are held at a predetermined level. Two calculations using the yield response function give insights into the interval where production can be expected to occur and the amount of water consumed.

First, the average product is the total output divided by units of input. For example,

assume that 18 inches of water would produce 125 bushels of corn. The average product equals 125 bushels divided by 18 inches which is 6.94 bushels of corn per inch of water. Assuming a farmer's use of water has no impact on the price of water, and the average product of water is increasing, the per unit cost of a bushel of corn will always be reduced by adding more water.

Mathematically, average product of water is depicted in Equation 2.3. This equation calculates average product of X_1 by dividing total production, Y, by the quantity of the input, X_1.

$$\text{Average Product of Water} = \frac{Y}{X_1} = \frac{f(X_1 \mid X_2, X_3, X_4, X_5)}{X_1} \qquad (2.3)$$

The second calculation, marginal product of water, is the change in output created by the last unit of water consumed. For example, assume that 18 inches of water produces 125 bushels of corn and 18.1 inches of water produces 126.2 bushels of corn. The marginal product would be 1.2 bushels divided by .1 inches which is 12 bushels of corn per inch of water.

Mathematically, marginal product of X_1 is the first partial derivative of the production function with respect to X_1 as written in Equation 2.4. The symbol f_1 represents the first partial derivative with respect to the variable X_1.

$$\text{Marginal Product} = f_1(X_1 \mid X_2, X_3, X_4, X_5) \qquad (2.4)$$

Figure 2.1 graphically depicts a typical production function and shows the

relationships between total product, marginal product, and average product.

Using concepts based on average and marginal product calculations, three stages of production can be identified. These stages of production are defined by the impact increasing amounts of an input have on production. Logically speaking, if adding a unit of input increases the average output, additional units of input would be added until the average output reaches its maximum. Stage I of production ends where the average

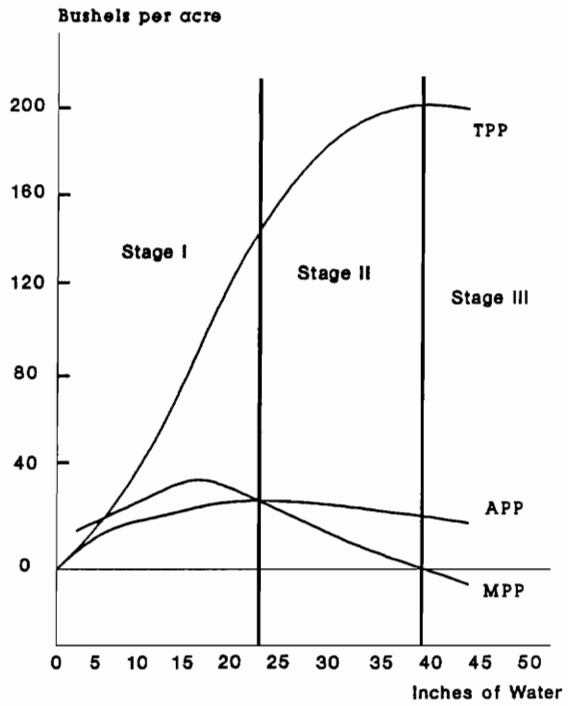

Figure 2.1. Relationships between Total Production and Marginal & Average Product

product reaches its peak. Next, if adding an additional unit of input causes total production to decrease, this additional unit would not be added. Where total output starts declining is the start of stage III. Finally, stage II is defined as the area between where stage I ends and stage III begins.

Stage I is the interval of production where average product is increasing. Stage I is an irrational area to manage any irrigation system as the per bushel production cost of corn can be lowered by adding more water, because the amount of water used to produce the average bushel of corn is reduced. Assuming the cost of water is constant, the average cost of production would fall as additional water is applied in stage I.

Stage III begins where the marginal product becomes negative and where total production starts to decrease. In stage III the old cliche of "too much of a good thing is too much of a good thing" is realized. In stage III water is added until the field becomes waterlogged causing the corn roots to be deprived of oxygen, and corn production is actually reduced. Stage III of production is an irrational area to produce, because corn production is lowered by adding additional units of water and per unit cost is increasing while revenues are falling.

Stage II becomes the only area on the production function where a rational entrepreneur would manage his operation. As Figure 2.1 shows, marginal product and average product are falling when producing in stage II. If the cost of water were zero, the operation would be managed to produce the highest possible yield technically feasible, because production could continue to increase without incurring any cost. As

the cost of water rises from zero, the value received from the additional water would have to equal the cost of the additional water or the additional water would not be added. Equating the cost of water and the value received from the water will determine where the entrepreneur produces in stage II.

2.3 Relationship Between Production and Cost

As stated above, a rational producer would operate in stage II. However, this information does not specify the point where monetary returns are maximized. Since the goal of the producer is defined to be the maximization of monetary returns; and resources are assumed to be limited, the producer strives to maximize production from a limited pool of resources (Henderson and Quandt).

The amount of input used is directly related to the amount of product produced. This relationship allows the cost function to be related to the production function. In fact, the cost function can be viewed as a function of the production function, price of inputs, and fixed cost. In the case of one variable input, irrigation, X_1, the total cost function may be represented as written in Equation 2.5.

$$C = f(Y, r_1 \mid r_2, r_3, r_4, r_5) + FC \qquad (2.5)$$

where:

- C = total cost of production;
- Y = production function;
- r_i = price of input i; and
- FC = fixed cost associated with operation.

2.3.1 Variable Versus Fixed Cost

There are two components of cost with one being a fixed component and the other being a variable component. The difference between variable and fixed cost is based on whether the decision to use or not use more of an input can be made, variable cost, or whether the cost of the input must be incurred whether production takes place or not, fixed cost. For example, prior to purchasing an irrigation system, the cost of this system can be viewed as a variable cost, but once the system has been purchased, it is a fixed cost and becomes a cost that must be absorbed by the operation.

Time is an important part of defining cost as being variable or fixed. Planning takes place in the long run where the operator can choose which investment will yield the highest returns (Gould and Ferguson). This study analyzes returns expected from an irrigation system investment. Therefore, all cost could be considered variable in this study. However, the economic analysis of the investment in the irrigation system assumes the system is purchased so the variable operating costs as well as fixed investment cost can be analyzed.

This distinction between variable and fixed cost is important because decisions will be changed based on how cost is defined. Fixed cost will not have an impact on annual production decisions, because this cost must be absorbed by the operation even if the producer decided not to plant the crop. For example, prior to purchasing a center pivot system, this cost is variable because by buying the system production will increase. However, once the purchase has been made and the structure built, all investment costs

associated with the structure will be paid whether the structure is used or not. Since fixed cost must be paid, the decision to use or not use the system is based on covering those expenses that are controllable, which are the variable costs.

Variable costs are controllable and do impact production levels. For example, the cost to apply irrigated water is a decision that is made every time the irrigation system is operated. If the system is not operated while corn is in a water short condition, yields will be reduced. If the system is operated, the cost will be absorbed, but yields and revenues will be increased. With variable cost, expected revenues and cost associated with the additional inputs can be compared versus fixed cost which will be absorbed independent of production and revenues.

2.3.2 Marginal Cost

Marginal cost is the marginal change in cost when output is marginally changed. A change in output occurs when the amount of inputs is changed. A change in Y will be associated with a change in cost of production. By differentiating the total cost function with respect to output, marginal cost for this one variable input production process is defined as follows:

$$MC = dC/dY$$
$$MC = r_1 * dx_1/dY \qquad (2.6)$$

given that: $MP = dY/dx_1$

substituting: $MC = r_1*(1/MP)$

where:

MC	= marginal cost;
d(C)/d(y)	= change in irrigation cost with respect to a change in output;
r_1	= price of irrigation; and
dx_1/dY	= change in x_1 associated with small change in Y.

In Equation 2.6, marginal cost is defined to be inversely related to the marginal productivity of the input multiplied by the price of the input. Logically, as marginal product increases; and the productivity of the marginal unit is higher, the marginal cost of the last input would be reduced, because of its increased productivity. Conversely, when marginal product starts decreasing; and the productivity of the last unit is lower; the marginal cost of the last unit is increased, because of its decreased productivity.

2.3.3 Average Variable Cost

As is true with marginal cost, there is an analogous relationship between average cost and average product for a one input production process. As average product increases, productivity of the average input is increasing, and the average cost of the input would fall. On the other hand, when average product starts decreasing, average productivity is falling, and the average cost of the input is rising. Mathematically, the inverse relationship between average variable cost and average product is shown in Equation 2.7 for the one input case.

$$AVC = TVC/y$$

given that: $TVC = r_1 * x_1$

substituting: $AVC = r_1 * x_1 / y$ (2.7)

given that: $AP = y/x_1$

substituting $AVC = r_1/AP$

where:
- AVC = Average Variable Cost;
- TVC = Total Variable Cost;
- Y = Total Production;
- r_1 = price of input x_1;
- x_1 = level of demand for this input; and
- r_1x_1 = cost of irrigation associated with input x_1.

2.4 Relating Theory to this Study

The concept of marginal analysis is used to construct the design models. Since irrigation in Virginia only supplements natural rainfall, corn will grow and produce positive returns without irrigation. If irrigation is added to the production process, this added cost must be justified by an increase in production and ultimately in revenues. The basic assumption that is made in this analysis is that corn production is a profitable enterprise in parts of Virginia. Therefore, if the increased revenues from irrigation cover the additional irrigation cost, irrigation is assumed to be beneficial.

As previously shown, cost functions are directly related to production functions. Maximizing profits is a stated goal used in modeling individual behavior in economic analysis of the production process. The following analysis of profit maximization, using the one variable input case, shows the theoretical implications of the cost models and how theory relates to this study. The symbol used in this study to represent profit is Z.

$$Z = P_o*Y - r_1*x_1 \qquad (2.10)$$

using the first order condition for π maximization yields:

$$dZ/dx_1 = P_o*dY/dx_1 - r_1 \quad (2.11)$$

setting Equation (2.11) equal to zero yields:

$$P_o*dY/dx_1 - r_1 = 0 \qquad (2.12)$$

$$P_o*dY/dx_1 = r_1 \qquad (2.13)$$

As stated in Equation 2.13, input x_1 will be added until the price of the output multiplied by the marginal productivity of x_1 equals the cost of the input. Economically stated, the marginal value product of x_1 equals the price of x_1 where profits are maximized. This concept will be used in Chapter 5 to show how these models can be used to make management decisions.

Profit maximization has a dual focus as a producer tries to maximize production while working under the cost minimization constraint. This makes the producer use the resources efficiently to achieve the highest yield possible within this resource constraint. Therefore, profit maximization can be analyzed from the cost perspective to yield:

$$Z = P_o*Y - c(Y) \qquad (2.14)$$

using the first order condition for profit maximization yields:

$$Z = P_o - dc(Y)/dY \qquad (2.15)$$

setting equation equal to zero yields:

$$P_o - dc(Y)/dY = 0 \qquad (2.16)$$

$$P_o = dc(Y)/dY \qquad (2.17)$$

$$P_o = MC \qquad (2.18)$$

As shown in Equation 2.18, inputs will be added to the production process until the marginal cost equals the price of the output. By substituting MC for P_o from Equation 2.18 into Equation 2.13, marginal cost can be directly linked to the marginal product of the input as follows:

$$MC*dY/dx_1 = r_1 \qquad (2.19)$$

$$MC = dx_1/dY*r_1 \qquad (2.20)$$

$$MC = r_1/(dY/dx_1) \qquad (2.21)$$

given that: $MP_1 = dY/dx_1$ (2.22)

substituting: $MC = r_1/MP_1$ (2.23)

This study focuses on the cost side of the production function and cost function relationship. Computer models are developed to estimate the additional cost associated with irrigation. These programs are utilized to create a database of costs and factors that affect these costs. This database is analyzed to build econometric irrigation cost models which estimate the cost associated with the irrigation system as a function of the agronomic, meteoreological, and economic variables that impact irrigation cost.

Combining the relationships between cost and production supported by theory and the cost models created in this study, the results of this study can be used to improve the decision making process as related to the management of supplemental irrigation systems.

By combining the assumed yield response expected from an irrigation system with the expected cost associated with the purchase and operation of the irrigation sytem, a better rationale decision can be achieved. Once the system is purchased, the marginal cost of operating the irrigation system can be compared to the expected benefits to decide whether the system should or should not be used.

This study estimates the expected annual cost of irrigation. This expected annual cost would be used with the assumed yield response and expected benefits derived from irrigation to determine if this purchase would be a good decision or not. Also, this annual cost is split between a variable cost which estimates the annual cost of operating the system, and an annual fixed cost which accounts for depreciation and other annual expenses unrelated to the system's operation. This split between variable and fixed costs facilitates a more detailed analysis of the expected variable costs which can be used in a marginal analysis of the operating expenses to determine if the expected benefits from operating the system will surpass the marginal cost.

CHAPTER 3

The Design Models

Estimating the annualized cost of irrigating field corn in Virginia with a portable pipe, fixed big gun, traveling gun, and center pivot systems is the primary focus of the irrigation design models. Portable pipe and fixed big gun systems utilized one design model; traveling gun and center pivot systems utilized separate models. Three models are required so the different equipment and field designs can be accurately estimated. Once field design is completed and equipment cost analyzed, the models employ similar logic to estimate the parameters which are used to compute cost.

These design models were created on MS-DOS personal computers using BASIC as the language. The computer programs encompass the knowledge of experts in the field of irrigation design. Through many conversations with irrigation equipment dealers and experts in the irrigation field, the design models were refined until their cost estimates reflected their expertise (Ross, Booth, and Brantley). Finally, this chapter draws heavily on the Virginia Water Resources Research Center's bulletin 146, Assessing the Feasibility and Potential Expansion of Large-Scale Riparian Irrigation in Virginia (Taylor, Ross, Vellidis, and Lanier). Unless otherwise noted, the parameters presented in this chapter come from that source.

All of these models have 7 sections to them as follows:

1) assigning values to static parameters;

2) randomly selecting values for the stochastic parameters;
3) calculating operating time, water flow requirements, and designing the layout of the irrigation system;
4) calculating friction loss and determining horsepower requirements;
5) calculating annual variable cost;
6) calculating annualized fixed cost; and
7) summing annual total cost and calculating the increased yield required to break-even on irrigation investment.

Since the four models have a similar design, the discussion in all of the sections, except for Sections 3.4, 3.5, and 3.6, apply to all four models with differences among the models noted. These three sections have many assumptions which differ across the four models, so Section 3.4 focuses on the portable pipe and fixed big gun system. Section 3.5 focuses on the traveling gun system, and Section 3.6 focuses on the center pivot system. The computer codes for the design models are contained in Appendix A.

3.1 Assigning Values to Static Parameters

As variables that appear in the computer code are introduced in this chapter, their variable name will be indicated in parenthesis, following their introduction. The static parameters are based on agronomic or engineering principles. The engineering parameters will be discussed in the sections devoted to designing the different irrigation systems. This section will discuss the agronomic parameters, and specifically, rooting depth (RD), trigger point (TP), plant available moisture content of the soil (AMC), inches of water absorbed per hour (IPH), and the cost of increased inputs needed to support the additional yield (BI).

Calculating the number of drought days utilizes information on rooting depth, irrigation trigger point, and plant available moisture content of the soil. The number of drought days calculation is based on the work of Van Bavel and Lillard as updated by Vellidis, Ross and Taylor. The calculation for the number of drought days is based on a soil water balance. This calculation assumes that the soil water balance is 100 percent on April 1 of each year, adds rainfall to the soil water balance, and subtracts evapotranspiration from the soil water balance on a daily basis during the season.

The soil water balance sheet developed for this study is based on soils with moisture holding capacities of two, four, or six inches of water. To connect the soil moisture holding parameters to the expected number of drought day information, the assumption is made that 50 percent of the total plant available water will be used by the plant which is the irrigation trigger point. Plant available water is defined to be 50 percent of total available water or one, two, or three inches of water could be used before the field must be irrigated or receive natural rainfall.

Before the total water available to the plant could be determined, the soil zone where the soil water would be managed, had to be defined. For field corn with no soil impediment, the root zone has a depth of approximately 30 inches. The rooting depth (RD) is set to 30 inches in all the models (Huebner).

Trigger point (TP), is the percent of available water where the operator will start running the irrigation system. The trigger point is assumed to be the percent of available water just above the point where the plant is stressed. The plant available soil moisture

is defined as the soil water with a soil tension above the wilting point coefficient. Fifty percent of plant available soil moisture content is the point where corn will start being stressed and is the figure used in all design models for the irrigation trigger point (Huebner).

Equation 3.1 calculates the plant available soil moisture by using available water holding capacity (BASIS) multiplied by the trigger point and dividing by the rooting depth of corn to yield the inches of plant available water per inch of soil. Once this water is consumed, the irrigation system would be used to put more water into the soil.

$$AMC(I) = (BASIS*TP)/RD \qquad (3.1)$$

where:

AMC = Available Moisture Content of Soil I;
BASIS = Inches of Water Available to Plant;
TP = Percent Available Water that Starts System Running; and
RD = Rooting Depth of Corn in inches.

The number of drought days calculations (Vellidis, et al.) is linked to the design models through Equation 3.1 by BASIS. BASIS is assumed to be the total soil water above the permanent wilting point. Since the irrigation system would be used and a drought day would occur when this reservoir of water reached 50 percent, each water level can be multiplied by two to yield BASIS. Therefore, a one, two, and three inch soil, as defined in Van Bavel's work, would yield a two, four, and six inch BASIS in this study.

To link this information to the soils of Virginia, BASIS is divided by the 30 inches of soil to yield total plant available soil water content of 0.0667, 0.1333, and 0.2 inches

of water per inch of soil. These figures correspond with soil types of low, medium, and high water holding capacity. This soil water holding spectrum covers the range of soil types in Virginia relative to their ability to hold total plant available soil water (Jensen, et al). Also, these soil types which hold 0.0667, 0.1333, and 0.2 inches of water per inch of soil absorb water at a rate of 0.5, 0.3, and 0.4 inches of water per hour, respectively (Jensen, et al).

Once the available soil moisture content of soil is determined, other soil parameters are defined. First, yield per acre without irrigation, and production budgets for these three moisture holding capacity soils are developed (Taylor, et al). Also, an additional production budget is created for 190 bushel per acre corn which is the assumed yield for irrigated corn.

Outside these budgets, yields have a marginal impact on irrigation cost through lost production due to land lost to the physical nature of the irrigation structure. When computing the revenue change between non-irrigated and irrigated fields, the non-irrigated yields would be greatly reduced in droughty years and this difference must be computed if reasonable irrigation benefits are computed. However, in this study the yields of 80, 100, 120, and 190 for the low, medium, and high water holding soils; and the irrigated soil, respectively, are held constant when computing cost. Over the life of the irrigation system, these averages yield realistic figures, but year-to-year fluctuations could be great and these fluctuations would impact cash flow.

Irrigation allows corn to be planted more densely than without irrigation. The more corn plants per acre the more nutrients the plants need, the more crop harvesting and storage systems must handle, and cost will increase. The design models accounted for this increase in cost by using different budgets for the three water holding capacity soils. By subtracting the expected expenses without irrigation from the expected expenses with irrigation, the additional input cost (BI) associated with irrigation for each soil type is determined (Taylor, et al.).

Since water is the limiting factor in this analysis, as the available water increases, so does yield. The 80 bushel per acre budget corresponds to a two inch BASIS soil that holds 0.067 inches of water per inch of soil to a 30 inch depth, the 100 bushel per acre budget corresponds to a four inch BASIS soil that holds 0.133 inches of water per inch of soil to a 30 inch depth, the 120 bushel per acre budget corresponds to a six inch BASIS soil that holds 0.2 inches of water per inch of soil to a 30 inch depth, and the 190 bushel budget corresponds to any of these soils that are adequately irrigated (Ross).

Table 3.1 lists the expenses of the individual items in the budget. Total cost increases from $262.59 for the 80 bushel per acre budget to $359.99 for the 190 bushel per acre budget, due to an increase in plants per acre, nutrients, and increased harvest costs due to higher potential yields. From the perspective of determining the increased cost associated with irrigation, the relative differences among these budgets are more important than the absolute numbers themselves. Note that the budget for 190 bushel corn does not include irrigation cost.

Table 3.1. Corn Production Budget Excluding Irrigation Expenses[b]
1984 Prices for Various Yields on a Per Acre Basis

	Water Holding Capacity (in.)			
Variable Cost	TWO	FOUR	SIX	Irrigated Soil
Corn Yield (Bu./Ac.)	80	100	120	190
Preharvest Expenses				
Seed Corn (Bu.)	$18.00	$20.40	$22.80	$27.00
Nitrogen (Lbs.)	$31.05	$36.45	$40.50	$47.25
Potash (Lbs.)	$12.00	$14.40	$14.40	$18.00
Phosphate (Lbs.)	$7.50	$9.00	$9.00	$11.25
Micro Nutrients (Lbs.)	$0.00	$0.00	$0.00	$12.00
Fertilizer App. ($/Ac.)	$4.50	$4.50	$4.50	$4.50
Aatrex 4L (Qt.)	$5.56	$5.56	$5.56	$5.56
Dual 8E (Pt.)	$13.18	$13.18	$13.18	$13.18
Chemical Application ($/Ac.)	$4.50	$4.50	$4.50	$4.50
Lime (Tons)	$7.50	$7.50	$9.90	$9.90
110Hp-15Ft-Rotary Cutter ($/Ac.)	$4.39	$4.39	$4.39	$4.39
110Hp-5-16-Plow ($/Ac.)	$5.43	$5.43	$5.43	$5.43
110Hp-18Ft-Disc ($/Ac.)	$3.40	$3.40	$3.40	$3.40
50Hp-12Ft-Spring-Harrow ($/Ac)	$0.85	$0.85	$0.85	$0.85
70Hp-4Row Planter($/Ac.)	$3.68	$3.68	$3.68	$3.68
Pre Harvest Labor($/Hr.)	$6.48	$6.88	$6.96	$7.20
TOT. PRE-HARVEST EXP.	$128.02	$140.12	$149.05	$178.09
Production Interest (6 Mo.)	$7.68	$8.41	$8.94	$10.69
Harvest Expenses				
Combine-4 Row ($/Ac.)	$10.29	$10.29	$10.29	$10.29
Harvest Labor ($/Hr.)	$2.32	$2.32	$2.32	$2.64
Hauling (Bu.)	$12.00	$15.00	$18.00	$28.50
Drying (Bu.)	$20.00	$25.00	$30.00	$47.50
TOT. HARVEST EXPENSE	$44.61	$52.61	$60.61	$88.93
Total Variable Cost	$180.31	$201.14	$218.60	$277.71
Total Fixed Cost-Machinery	$82.28	$82.28	$82.28	$82.28
Total Cost	$262.59	$283.42	$300.88	$359.99[a]

[a] Excluding the cost of owning and operating the irrigation system
[b] Taylor, et al.

The cost for a two inch BASIS soil holding 0.067 inches of water per inch of soil is $262.59 per acre. If this soil is irrigated, the cost would increase to $359.99 per acre. The difference between the irrigated cost and the non-irrigated cost is $97.42 per acre. This calculation determines the increased cost of extra inputs associated with irrigation for the other water holding capacity soils (BI).

The soil type (ST) associated with the different water holding capacity soils, the rate the soil will absorb water (IPH), the expected corn yields without irrigation (YPA), and the increased cost per acre of additional inputs (BI) are defined in these models based on the water holding capacity of the soils. Also, an index (I) is used throughout the design models to match the soil information with various parameters. For example, YPA(3) would be the variable used to identify the yield per acre for a high water holding capacity soil. The values used for these variables are listed in Table 3.2 (Taylor, et al.). For example, the cost of additional inputs (BI) ranges from $59.14 to $97.42 for the three soil types.

Table 3.2 lists all the soil parameters associated with each of the three water holding capacity soils. A low water holding capacity soil is typically a coarse soil that drains quickly leading to a soil that holds relatively little water, and absorbs water relatively quickly. It has low fertility which increases fertilizer cost, and has relatively low yields. The medium water holding capacity soil is typically a finer textured soil which holds relatively high volumes of water, but it holds this water so tightly that much of this water is unavailable to the plant. Medium water holding capacity soil absorbs water

Table 3.2. Agronomic Variables Defined by Soil Type

ST(I)	IPH(I)	AMC(I)	BI(I)	YPA(I)	I
HIGH	0.4	0.200	$59.14	120	3
MEDIUM	0.3	0.133	$76.57	100	2
LOW	0.5	0.067	$97.42	80	1

where:
ST = Description of type of soil;
IPH = Inches of water the soil can absorb in 1 hour;
AMC = Available moisture content of soil in inches per inch of soil;
BI = Cost of additional inputs needed to support the irrigated yield in dollars per acre; and
YPA = Yield per acre in bushels without irrigation.

relatively slowly, and has medium fertility and yields. The high water holding capacity soil is typically a loamy type soil which holds the most plant available water, has the highest fertility, and yields; and has a medium ability to absorb water.

3.2 Randomly Selecting Values for Stochastic Parameters

Since the purpose of this thesis is to estimate the cost of irrigating corn in Virginia, the design models are used to create a database that can be statistically analyzed. Twelve variables are selected as random variables so that the model could be summarized by a statistically estimated equation. This statistically estimated equation will yield an estimated irrigation cost for each unique situation versus running the design model for each situation. Even though the statistical equations lose some of the accuracy of the

design models, the time saved in analyzing the many potential field sites throughout Virginia will be very advantageous in the next phase of this project.

These random variables have geographical, financial, meteorological, or agronomic bases. These variables are chosen as they are judged to be stochastic and have a significant impact on irrigation cost. Each variable is given a range, which is based on the previous work done by Taylor, et al. The design models randomly selected numbers within this range. The equations estimated from these simulations are valid predictors of irrigation cost as long as the values given to the variables fall within their ranges.

Table 3.3 summarizes this information. For example, number of drought days, NOD, ranged from 6 to 123 days, and real interest rate, IR, ranged from 0.05 to 0.25. Ranges for NOD, ACRE, HD, VD, and IR are taken from the models explained in Assessing the Feasibility and Potential Expansion of Large-Scale Riparian Irrigation in Virginia by Taylor, et al, except the range on IR has been expanded from .05 - .2 to .05 - .25. Since all prices of the irrigation components are in 1983 dollars, the interest rate is a real rate where inflation has been subtracted from a risk free nominal rate. Three month treasury bill rate is used to reflect the risk free nominal interest rate and prices received from all farm products is the inflation index used.

From 1974 through 1989, the three month treasury bill rates have fluctuated from a low of 4.99 percent in 1976 to a high of 14.03 percent in 1981 (Council of Economic Advisors). Over the same period, the index of prices received from all farm products fluctuated from a low of -9.86 percent in 1985 to a high of 15.0 percent in 1978

Table 3.3. Exogenous Variables and Their Ranges

EXOGENOUS VARIABLES	SYMBOL	RANGE	UNITS
METEOROLOGICAL VARIABLE			
Number of Drought Days	NOD	6 - 123[a]	DAYS
GEOGRAPHICAL VARIABLES			
Size of Field to be Irrigated	ACRE	1 - 300[a]	ACRES
Distance--Edge of Field to Water Source	HD	50-15,840[a]	FEET
Height of Highest Riser from Water Source	VD	5 - 300[a]	FEET
FINANCIAL VARIABLES			
Cost of Diesel Fuel	CE	0.75-1.50	DOLLARS
Cost of Power Source per Horsepower	CHP	125 - 225[a]	DOLLARS
Interest Rate	IR	5 - 25	PERCENT
Selling Price of Corn	CROPPC	1.39-5.56	$ Per BU
Labor Wage Rate	WAGERT	3.35-6.70	$ Per Hr
AGRONOMIC VARIABLE			
Corn's Daily Consumption of Water	CU	0.2-0.25	IN./DAY

[a] only interger values are selected

(USDA). Subtracting the inflation factor from the risk free nominal interest rate yields a risk free real interest rate for agriculture which has fluctuated from a low of -7.78 percent in 1978 to a high of 17.34 percent in 1985 and averaged 5.33 percent over this period.

The risk premium for agriculture must be added to the risk free real interest rate to calculate the real interest rate for agriculture. The historical average for investments in agriculture is 5.6 percent (Bosch, Taylor, and Ross). By adding this value to the risk free

real interest rate, the real return that a producer would need from an investment to cover the risk involved in this investment has fluctuated from a low of -2.18 percent in 1978 to a high of 22.94 percent in 1985 and averaged 10.93 percent over this period.

The real interest rate, IR, ranges from 5.0 percent to 25.0 percent in the irrigation models. Since this is a long term investment, the average real rate of return of 10.93 percent is a good reflection of the average investment cost in agriculture and the return an average investor would need before making this investment. However, the ranges used in the models of 5.0 percent to 25.0 percent makes the models more flexible to meet individual's risk preferences. A risk taker may feel comfortable basing the decision on a 5.0 percent return rate and a risk averse person may base the decision on 25.0 percent return rate. Historically, the real interest rate in agriculture has fluctuated greatly and the ranges in the models give them flexibility to meet an individual's preferences.

Table 3.4 lists the number of drought days that occur once in a 10 year period across five Virginia regions from April 1 through August 31 (Vellidis, et al.). Since 102 days is the maximum number of drought days expected in Virginia, as depicted in Table 3.4, and 123 drought days is the upper range used in the simulation of the design models, the statistical equations generated from this analysis will accurately reflect the worst plausible drought situation in Virginia.

Table 3.4. Maximum Number of Drought Days in 1 out of 10 Years in Virginia for 183 Day Growing Season

	Soil Water Capacity (BASIS)			
Area[1]	2 inch	4 inch	6 inch	Growing Season
A	35	53	80	April 1 to August 31
B	51	67	91	April 1 to August 31
C	65	79	99	April 1 to August 31
D	71	84	102	April 1 to August 31
E	68	81	101	April 1 to August 31
MAXIMUM	71	84	102	

[1] See appendix B for a map of Virginia showing these areas.

The variables, CE, CHP, CROPPC, WAGERT, and CU, all have subjective ranges calculated by using the points used by Taylor, et al. in Assessing the Feasibility and Potential Expansion of Large Scale Riparian Irrigation in Virginia and logically calculating the ranges. The point estimate for CE was $1.25 per gallon of diesel fuel and the range in the models is $0.75 to $1.50 per gallon as fuel prices have actually dropped since 1983. The point estimate for CHP was $150 per horsepower and the range in these models is $125 to $225 per horsepower to account for the pricing variability with the different quality engines. The point estimate for CROPPC is $2.782 per bushel and the range in these models is $1.39 to $5.56 per bushel as the range is 50 percent and 100

percent of the original point estimate. The point estimate for WAGERT was $4.00 per hour and the range in these models is $3.35 to $6.70 per hour where $3.35 is the minimum wage and $6.70 is the minimum wage doubled. The point estimate for CU is .25 and the range in these models is .2 to .25 inches per day.

The acreage each irrigation system can irrigate has natural boundaries as shown in Table 3.5. The upper limit of 80 acres for the portable pipe system and fixed big gun system are based on the time required to move the system between sets and the limited amount of time available to irrigate the field.

Table 3.5. Size of Field Irrigated by Type of System

	TOTAL ACRES IRRIGATED	
Type of System	Minimum	Maximum
Portable Pipe	1	80
Big Fixed Gun	1	80
Traveling Gun	10	110
Center Pivot	30	300

The traveling gun system is restricted to an upper limit of 110 acres for the same reasons as the portable pipe system; and due to the engineering limitations and the pumping inefficiency imposed by pumping large volumes of water. The center pivot

system is restricted to an upper limit of 300 acres due to engineering limitations and the pumping inefficiencies imposed by pumping large volumes of water.

All systems had an upper limit but the traveling gun and center pivot systems have large fixed expenses that must be spread over a reasonable amount of acreage, so a minimum of 10 and 30 acres are placed on these systems, respectively. No irrigation system in Virginia is known to violate these limitations (Ross).

3.3 Designing the Irrigation System

The logic used to design the portable pipe, fixed big gun, and traveling gun systems is based on the following rules:

1) water will be pumped as fast as the soil will absorb it;
2) the plant available water will be at 50.0 percent of its capacity when irrigation begins;
3) each irrigation will return the field's plant available water to 100 percent; and
4) the number of acres irrigated per setting or run will be minimized.

Design rules one and four limited capital expenses--a fixed cost, while they maximized labor cost--a variable cost. Rules two and three maximized the amount of water irrigated each year by replacing 50 percent of the total water needed to bring the soil water to full capacity.

The design rules for the center pivot system are much more straightforward as follows:

1) the center pivot arm runs to the edge of field;

2) the plant available water is at 50.0 percent of its capacity when irrigation begins;
3) each irrigation will return the field's plant available water to 100 percent; and
4) the irrigation system will run 24 hours a day when the field is under drought conditions.

The design rules for the center pivot system are straightforward. Fixed cost will be very accurate for this system as the design of a center pivot system has limited options. A potential bias is related to the management philosophy embedded in the simulation models. Since the complications of managing labor are almost nonexistent with a center pivot system, an operator might prefer to operate the system when plant available water is 70 percent of its potential and put down less water each irrigation. If a producer desires to use this philosophy to operate the center pivot system, the design developed in this thesis would be biased. This bias would be to underestimate the annual variable cost, because the volume of water running through the system is assumed to be the minimum needed to irrigate the field and this 70 percent irrigation philosophy would increase the amount of water pumped by the system.

Another problem in irrigation management is deciding when water needs to be applied. The rule used in these models state that the systems will start applying water when the soil water reaches 50 percent of field capacity. This is a simplistic approach that produces a decision rule, but is impractical to use in the actual situation, because of the lag between starting the irrigation system and completely irrigating the field. This lag could be three days and the operator who starts irrigating when the field

reaches 50 percent of field capacity will stress the crop that is irrigated last. To keep from stressing the crop, irrigation may have to start at 70 percent of field capacity. This study assumes the field is irrigated instantaneously once the soil water reaches 50 percent of field capacity.

In addition, note that all of these design rules may operate differently from what is observed in practice. That is, once the system starts operating, the design models assume that the entire field will be irrigated even though a rational operator would turn the system off if there is a high probability of rainfall. In the real world, farmers would have many options and an individual may operate his system more efficiently than these models assume.

Following the above discussion on the logic of these models from a conceptual perspective, the following discussion details the specific characteristics of the three design models as follows:

1) portable pipe and fixed big gun systems;
2) traveling gun system; and
3) center pivot system.

3.4 Portable Pipe and Fixed Big Gun Systems

Due to the similar design of the portable pipe and fixed big gun system, one model is constructed to simulate the cost of constructing and running these two systems. The difference between these systems is that one sprinkler in the portable pipe system covers .065 acres versus one fixed gun in the fixed big gun system which covers 0.584 acres.

This difference affects the cost of sprinklers, the water pressure required, and labor hours required to move the system, but the design of each system is relatively the same.

First, the model assumes the field is square and the submain is laid across the middle of the field. Laying the submain across the middle of the field minimizes capital outlays. If the submain is laid across the end of the field; and a lateral did not run the full length of the field, additional lateral pipe would have to be purchased. Chances of this happening when the submain is laid across the middle of field are reduced.

Since the entire field is not covered by the irrigation system in one set, time becomes an important parameter. Time is constrained by the rule that water is applied at least as fast as the plant can withdraw it. The following equation calculates the number of days required to irrigate the entire field (DPI).

$$DPI = (AMC(I) * MIN * (1 - TP))/CU \qquad (3.2)$$

where:

DPI	=	Days to completely irrigate field;
AMC	=	Available moisture content of soil I (in./in.);
MIN	=	Depth of root growth (inches);
TP	=	Percent of available moisture that turns system on; and
CU	=	Plant's daily consumption of water (inches).

The numerator of Equation 3.2 determines the total inches of water that must be applied during each irrigation (AMC), as the inches of total available water per inch of soil is multiplied by the total inches of root growth (MIN). This calculation determines the total inches of water available to the plant. Since the percent of available water left

in the soil determines when the system starts, the trigger point (TP), the total water available had to be multiplied by the percent of water that could be used by the plant. This calculation is made by subtracting the percentage of water that triggers the system to start operating from 100.0 percent, and multiplying this percent by the total plant available water which computes the amount of water that will be consumed before the system starts operating. Next, the inches of water to be consumed is divided by the inches of water a plant consumes each day to calculate the days available to irrigate the entire field.

Since these systems can not be operated 24 hours a day, due to the time used to move the system and the inefficiencies associated with operating these systems, the model assumed the system would be operating 18 hours a day with the extra 6 hours used to move the system and account for the inefficiencies. Equation 3.3 converts days per irrigation to hours per irrigation by multiplying days per irrigation by 18 hours per day.

$$HPI = DPI * 18 \qquad (3.3)$$

where:

HPI = Hours per irrigation;
DPI = Maximum days per irrigation; and
18 = Conversion factor from days to hours.

The other time constraint is the time used to put all the water in the soil. Before this time constraint could be calculated, the amount of water to be put in the soil had to be determined. Since the amount of water to be applied per irrigation equals the amount

of water that has been consumed, the plant's daily consumptive use is multiplied by the days needed to irrigate the entire field. This quantity is divided by the efficiency rate of irrigation, where inefficiencies include water losses due to evaporation, plant interception, and water run-off. The efficiency rate for these two systems is 70.0 percent (Turner, et al.). This calculation is specified in Equation 3.4.

$$WAI = (DPI * CU)/0.7 \qquad (3.4)$$

where:

WAI = Water applied per irrigation in inches;
DPI = Days per irrigation; and
0.7 = Irrigation Efficiency of System.

This design model assumes the water will be applied as fast as the soil will absorb the water. Since each soil type will absorb water at a maximum rate in inches per hour (IPH), Equation 3.5 is used to calculate the minimum time needed to replace the water in hours.

$$OHPS = WAI/IPH(I) \qquad (3.5)$$

where:

OHPS = Operating hours per setting;
WAI = Water applied per setting in inches; and
IPH(I) = Inches of water the soil can absorb in one hour.

Since the two time constraints have been determined, Equation 3.6 divides the total hours available to irrigate the field, 18 hours, by the minimum number of hours needed to apply the water per setting. Equation 3.6 calculates the number of settings required per day.

$$NOSPD = 18/OHPS \qquad (3.6)$$

where:

NOSPD = Number of settings per day;
18 = Hours system operates each day; and
OHPS = Operating hours per setting.

With the time constraints satisfied, the algorithm is programmed to determine the number of acres each setting irrigates based on the field being irrigated within the time constraint. In this algorithm, the number of sets per irrigation, acreage irrigated per set, and the number of sprinklers or guns per set are calculated.

The variable that is modified to satisfy the time constraints is the number of guns. Equation 3.7 uses the logic that the number of settings per day multiplied by the acres irrigated per setting multiplied by the number of days per irrigation equals the acres associated with the entire field. Sprinklers or guns are added until enough sprinklers or guns are available to irrigate the entire field within the time constraint.

IF (DPI*NOSPD*APG*GUN)/ACRE) <=1 THEN (ADD ONE SPRINKLER) (3.7)

where:

DPI = Maximum number of days per irrigation;
NOSPD = Number of settings per day;
APG = Acres irrigated per sprinkler or gun;
GUN = Number of guns per setting; and
ACRE = Acres in the entire field.

A fine tuning algorithm is used to keep the acres irrigated equal to the size of the field. For example, adding one more gun to the fixed big gun system adds 0.584 acres to each setting and the system could become too large for the field. The fine tuning algorithm uses the number of hours per irrigation as the compromising variable. This

fine tuning algorithm allows acres irrigated by the model to equal the acres associated with the field. Operating hours are continuously reduced by 0.5 percent until the acres being irrigated equals the acres associated with the field. Thus, each system will operate 18 hours or less.

3.4.1 Determining the Labor Hours Needed to Operate these Systems

The hours of labor needed to operate the two systems are broken down into two components. First, the labor needed to move the irrigation pipe and sprinklers from one setting to the next is calculated. This calculation is based on the number of acres irrigated per system multiplied by a factor. This factor associates labor-hours with irrigated acreage which is one labor-hour per acre for a portable pipe system, and 0.75 labor-hours per acre for the fixed big gun system (Turner, et al.). The fixed big gun system requires less time per acre to move since fewer sprinklers are moved. Equation 3.8 specifies this calculation.

$$LABHR = NOSPD * GUN * APG * LAB \qquad (3.8)$$

where:

LABHR = Labor-hours required to move each day;
NOSPD = Number of settings each day;
GUN = Number of sprinklers/guns per setting;
APG = Acres per gun;
LAB = Factor: 1 hour per acre for portable pipe; and
0.75 hours per acre for fixed big gun.

The number of laborers required to move the system is at least two individuals since moving a 30 foot pipe with one individual would be difficult. Using the author's

experience in moving a portable pipe system in tobacco, four people would be a realistic number to move these portable irrigation systems. Since moving four people to and from the field is time consuming, the model assumes 15 minutes to get each person to the field and 15 minutes to get them back to their other work. This time is added to the time required to move the pipe from one setting to the next setting to estimate the total labor-hours required to operate these portable pipe systems. Equation 3.9 lists the calculation to estimate the labor-hours required to move laborers to and from the irrigated field.

$$LABTRAN = 4 * NOSPD * 0.5 \qquad (3.9)$$

where:

LABTRAN = Labor-Hours Each Day for Transportation; and
NOSPD = Number of Settings per Day.

3.4.2 Determining the Footage of Pipe Needed

The sections of pipe are main, submain, and lateral. The main pipe runs from the edge of the water source to the edge of field; horizontal distance (HD) is defined to be this distance. The submain pipe starts where the main pipe ends, at the edge of the field, runs across the field, and stops a short distance from the far edge. The distance, between where the submain stops and the edge of field, equals the distance the water is sprayed from the sprinkler or gun. Equation 3.10 specifies the calculation used to determine the number of submain sections.

$$SS\% = (X - RADIUS)/30 \qquad (3.10)$$

where:

SS% = Number of submain sections (interger);
X = Width of field (feet); and
Radius = Distance water is sprayed from sprinkler; which is:
30 feet for a portable pipe system; and
90 feet for a fixed big gun system.

Calculating the length of lateral pipe is more complicated. If the layout of the lateral pipe needed to fulfill the required setting size is shorter than the length of the run, an equation similar to Equation 3.10 is used, because one lateral must run to the end of the field. However, in most cases the lateral would cover more than one run and Equation 3.11 specifies the calculation to determine the length of the lateral.

$$LL1A = ((GUN * 2) - 1) * 30 \qquad (3.11)$$

where:

LL1A = Length of Lateral Pipe (feet); and
GUN = Number of Sprinklers/Guns Needed.

Equation 3.11 works because two 30 feet sections are associated with each sprinkler. One pipe section is subtracted, because the last gun only needs one 30 feet section as there is no need to connect the last sprinkler to another sprinkler.

For the fixed big gun system, the same logic is used. Since a fixed gun in this system throws water 90 feet in both directions, six 30 feet sections are associated with each gun, except the last gun. The last gun needs only three 30 feet sections as there is no need to connect the last gun to another gun.

3.4.3 Water Flow Requirements of Systems

Acre-inches per hour is a water flow parameter stating the amount of water flowing through a pipe in one hour which would cover an acre with one inch of water. With Equation 3.12, the model calculates acre-inches per hour applied by the system by calculating the total acres irrigated by all the sprinklers/guns in a set given the fact that the systems are always pumping water as fast as the soil will absorb it.

$$AIPH = GUN * APG * IPH(I) \qquad (3.12)$$

where:

AIPH = acre-inches per hour;
GUN = number of guns per set;
APG = acres irrigated by one gun; and
IPH(I) = inches per hour of water absorbed by soil I.

The engineering equations that are used to calculate the pipe size requires gallons per minute as the flow parameter. Acre-inches per hour is directly proportional to gallons per minute, and one acre-inch per hour equals 453 gallons per minute (Jensen, et al.). Therefore, acre-inches per hour is multiplied by 453 to calculate gallons per minute.

3.5 Traveling Gun System

This model assumes the field is square, but the submain is laid at the end of the field for all fields smaller than 38.8 acres, and laid across the middle for all fields larger than 38.8 acres. The justification for this decision is that the flexible hose for a traveling gun system can not be greater than 1,300 feet (Ross). When the field is larger than 38.8 acres, the flexible hose would be longer than 1,300 feet, if the submain is positioned at

the end of the field. When the field is larger than 38.8 acres, the submain must be laid across the middle of the field, to keep from violating the 1,300 feet limitation; and the number of runs double and labor cost rises disproportionately with this field size.

Some of the logic from the portable pipe program carries through to the traveling gun program. The logic for Equations 3.2 through 3.4 remains the same, except the pumping efficiency rises from 0.7 to 0.75 (Turner, et al.). Logically, the design programs are similar, except the traveling gun moves down the run versus the portable pipe and fixed big gun systems are fixed during each setting.

An algorithm is created that works to design a system that can cover the field within the time limit. The variable that changes is the distance the water is thrown from the gun, length of spray, which is used to meet the time limitations. For example, as the length of spray increases, more acreage is covered per run, fewer runs are needed to cover the field, and less time is needed to irrigate the field.

To start this algorithm, length of spray starts at 175 feet and continues to increase until the time constraint is satisfied. With this information, the number of runs can be calculated as specified by Equation 3.13. This equation calculates the number of runs by dividing the width of the field by the diameter of the area covered by the spray.

Since above 38.8 acres the submain is laid across the middle of the field, the width of field is doubled to account for runs on both sides of the submain pipe. The variable used to track if the field is above or below the 38.8 acres field size is Y2. If Y2 equals 1, the field size is below 38.8 acres, and if Y2 equals 2, the field size is greater than

38.8 acres.

$$NUMR = (X * Y2)/(LS * 2) \qquad (3.13)$$

where:

NUMR = Number of runs (feet);
X = Width of field (feet);
Y2 = Doubles X if acres are above 38.8; and
LS = Length of spray (feet).

The length of the run, which is the distance the traveling gun travels, is a function of the length of spray and distance from the submain to the end of the field. As the length of spray increases, the length of the run for a given field decreases. This calculation is specified in Equation 3.14.

$$LRUN = Y1 - (LS* 2) \qquad (3.14)$$

where:

LRUN = Distance traveled by traveling gun (feet);
Y1 = Distance from edge of field to submain pipe (feet); and
LS = Length of spray (feet).

To calculate the time needed to irrigate the field, the speed of the traveler had to be determined. As specified in Equation 3.15, this calculation is based on the logic that the traveler will travel two times the length of spray in distance while irrigating a fixed spot of soil. Two times the length of spray, in feet, is the numerator and the denominator equals the time it takes to irrigate this spot. The time needed to irrigate this spot equals the time it takes to put the necessary water down as fast as the soil will absorb it. This time is calculated by dividing the inches of water applied per irrigation by inches of water the soil will absorb in one hour.

$$FTHR = (LS * 2)/(WAI / IPH(I)) \quad (3.15)$$

where:

FTHR = Feet per hour;
LS = Length of spray (feet);
WAI = Water applied per irrigation (inches); and
IPH(I) = Inches of water per hour that soil (I).

Using these calculated variables, the time needed to irrigate one run can be determined, by dividing the distance the traveling gun travels, by the speed of the traveler. The traveling gun starts where the water touches the edge of the field. Irrigating the edge of the field, creates a trade-off between fully irrigating this spot and putting too much water on other spots. This trade-off is handled by having the traveler sit fixed for three-fourths the time necessary to completely bring the soil water to full capacity before the traveler is allowed to move. This same procedure occurs at the other end of the run. As specified in Equation 3.16, these two independent time periods are added together calculating the total operating time per run.

$$TPR = (LRUN / FTHR) + (1.5 * (WAI / IPH(I)) \quad (3.16)$$

where:

TPR = Time per run (hours);
FTHR = Speed of traveler (feet per hour);
WAI = Water per irrigation (inches); and
IPH(I) = Speed water is absorbed by soil I (inches per hour).

To finish the time calculation, the length of time needed to move the traveler between runs (LABHR) is calculated and added to the time to complete each run (TPR). This yields the time needed to complete each run and move the traveler. By multiplying this amount by the number of runs per irrigation (NUMR), the time needed to irrigate

the field (TPI) is calculated. By comparing this amount to the time available to irrigate the field, the model could determine if the irrigation design is suitable for the field.

As stated earlier, the length of spray is decreased or increased until the traveling gun system meets the time constraints. The constraint allows a plus or minus 0.25 percent difference in the time the irrigation system needs to irrigate the field and the time the soil water reserves are consumed. To satisfy this constraint, length of spray is increased or decreased by 0.25 percent until the time constraint is satisfied.

3.5.1 Determining the Labor Hours Needed to Operate this System

As with the portable pipe system, labor hours are broken-down into two components. First, the time needed to move the system after each run is calculated by multiplying the acres irrigated during the run by 0.2 (Turner, et al). This states that for every acre irrigated the system will require one person 0.2 hours to set the system up for the next run. This calculation is specified in Equation 3.17.

$$LABHR = ((Y1 * (LS * 2))/ 43560) * 0.2 \qquad (3.17)$$

where:

LABHR = labor hours required to move the traveler;
Y1 = length of field from submain to field's edge (feet);
LS = length of spray (feet); and
43,560 = square footage in one acre.

The second component of labor hours is the time one person needs to get to and from the field, so the system can be moved. The same assumption is used in the traveling gun model as used in the portable pipe model, except the traveling gun system needs only

one person where the portable pipe system needs four people to move the system. For each run, one person will average 30 minutes traveling to and from the field. Therefore, total labor hours equals the sum of the time needed to get to and from the field plus time needed to move system.

3.5.2 Determining the Footage of Pipe Needed

The length of the main and submain are calculated the same in the traveling gun program as in the portable pipe program. The lateral pipe for a traveling gun is a flexible hose that is attached to the submain; and connected to a reel, which is attached to the gun on the platform. As the reel turns the hose wraps around it and pulls the traveling platform closer to the submain. Therefore, the length of the hose equals the distance from the submain pipe to the edge of the field minus the length of spray.

3.5.3 Water Flow Requirements of the System

The same logic used in the portable pipe system is used in this model where acre-inches is calculated first and then converted into gallons per minute. The difference in the systems does require a different calculation for the number of acres irrigated. Acreage irrigated is found by using the formula to determine the area of the circle and this area is divided by the square footage of an acre. Equation 3.18 lists the calculation for the acreage irrigated by the traveling gun.

$$APG = ((LS\hat{}2) * \pi)/43560 \qquad (3.18)$$

where:

APG	= Acreage irrigated by gun (acres);
LS	= Length of spray (feet); and
π	= Pie equals 22/7.

Acre-inches (AIPH) is calculated by multiplying acres irrigated by the maximum speed the particular soil will absorb the water in inches per hour. Acre-inches are converted into gallons per minute by multiplying the acre-inches by the 453 conversion factor.

3.6 Center Pivot System

The assumption with all other systems is that the field is square, but the center pivot program assumes the field is a circle. In the center of the field, the center pivot arm is affixed to a concrete pad and the arm rotates around this point. With this system, the submain pipe is nonexistent as the main pipe is attached directly to the center pivot arm and the center pivot arm is analogous to the lateral in the portable pipe system.

This system is completely automatic and is assumed to operate 24 hours each day during a drought day. This makes the design more straightforward than the other systems, since the system does not need to be turned off to be moved.

The length of the arm goes from the center of the field to the field's edge and the main pipe goes from the edge of the water source to the center of the field. Therefore, the size of the system and the layout of the system are known parameters and easily calculated.

Days per irrigation, which is the same calculation as in the other programs, is multiplied by 24 hours. This calculation determines the operation time per irrigation by transforming days into hours.

Water applied per irrigation is the same equation as found in the other systems, except 80 percent of water applied by the center pivot system is assumed to enter the soil (Turner, et al).

3.6.1 Determining the Labor Hours Needed to Operate this System

Since this system is completely automatic and does not require manual labor to reset the system after each run, the computation of labor hours is slightly different in this program than the others. The time needed to transport one person to and from the field is the same. However, determining the number of times this operator needs to visit and observe the system differs.

The time spent at the operation site is broken into two components. First, the program assumes the operator will spend one hour each time the system is started, and the system is assumed to start operating at the beginning of each irrigation cycle. Secondly, each day the system is operating, the operator will visit the site and observe the operation for 15 minutes.

3.6.2 Water Flow Requirements of System

The logic of the previous programs has been to minimize the capital investment, to

apply the water as fast as the field will absorb it, and to have a system that would completely irrigate the field in the time the field's soil water goes from full capacity to 50.0 percent of full capacity. The center pivot program is driven by the rule that says the field is irrigated in the time the field's soil water goes from full capacity to 50.0 percent of full capacity. This decision rule was deemed to be the best because if water is applied as fast as soil will absorb it, the volumes of water that would flow through the system would require pipe sizes unavailable with today's technology.

Gallons per minute is based on the acre-inch calculation, but with some modifications. Acre inches per irrigation are calculated and this is divided by the time the system is operated per irrigation to compute acre-inches per hour. Using the transformation factor of 453, acre-inches per hour are converted into gallons per minute as specified by Equation 3.19.

$$GPM = (AACRE * WAI * 453)/TPI \qquad (3.19)$$

where:

GPM = Gallons per minute;
AACRE = Size of field (acres); and
TPI = time per irrigation the system operates (hours).

3.7 Determining Horsepower Requirements

Since the irrigated acreage, pipe footage, and water flow requirements of each system are known, the velocity of the water, and friction loss in the system can be calculated. Once these factors are calculated horsepower requirements can be determined.

3.7.1 Determining the Diameter of the Pipes

An algorithm is used in the program to determine the diameter size of each different type of pipe. Equation 3.20 specifies the calculation for water velocity found in many hydraulic texts (Ross).

$$V1 = (0.408 * GPM)/(SD1\hat{}2) \qquad (3.20)$$

where:

V1 = Water velocity in the main pipe (feet per second);
GPM = Gallons per minute; and
SD1 = diameter of main pipe (inches).

Equation 3.20 details the calculation for the main pipe. Conceptually this equation is the same for the other types of pipe. One difference is that the lateral pipe GPM, for the portable pipe and fixed big gun systems only, is divided by the number of laterals. This calculation allows the velocity calculation to be based on the water flowing through one lateral. Since the traveling gun and center pivot system have only one lateral, calculating the average GPM per lateral is not necessary.

The velocity calculation starts with the lateral pipe, then moves to submain pipe, and finally to main pipe, or if the lateral pipe is not present, the same logic would hold as the velocity calculation would start with the last pipe the water moves through and work backwards. The pipe diameter calculation always starts where the previous level stops preventing the program from allowing water to flow from a smaller diameter pipe into a larger diameter pipe.

There is a trade-off when forcing water through a pipe. Forcing water through a smaller size pipe will increase energy use to overcome the increased friction loss; thus increasing the variable cost of the system, but decreasing fixed cost. On the other hand, forcing water through a larger size pipe will decrease energy use due to the decreased friction loss; thus decreasing variable cost, but increasing fixed cost (Ross). The algorithm kept increasing the diameter of the pipe until the water velocity falls below the maximum water velocity allowed by the model for various pipes; thus minimizing fixed cost. Table 3.6 lists the maximum water velocity by pipe section of system and type of pipe used in the velocity equations (Ross).

Table 3.6. Maximum Water Velocities in Feet per Second

Pipe Section	Type of Irrigation System			
	Portable Pipe	Big Fixed Gun	Traveling Gun	Center Pivot
Lateral Pipe	7.5	7.5	NA	NA
Submain Pipe	6.0	6.0	NA	NA
Main Pipe	6.0	6.0	6.0	6.0

Velocity of water is allowed to be higher in the lateral pipe than the other pipes, because the portable pipe and fixed big gun systems are multisprinkler systems. Gallons per minute will decrease when water is discharged as it passes each sprinkler. Therefore, after water has passed the first sprinkler, velocity will decrease (Ross). The

other systems, traveling gun and center pivot, are designed to handle higher water velocities and matrices are designed to select the proper arm length for the center pivot system and proper gun for traveling gun system; thus velocity is not a factor in their selection. These matrices are contained in Appendix A as they are detailed in the design programs.

3.7.2 Friction Loss

Determining the energy loss due to the friction created by the water moving along the surface of the pipe involves the pipe's diameter, water velocity, and the friction coefficient associated with the pipe's composition. In the models, four different pipe compositions are used with the main pipe being made of pvc material, the submain and laterals are made of aluminum, the flexible hose for the traveling gun is composed of a polyethylene, and the arm of the center pivot is made of steel.

Since the material's friction coefficient is a denominator in the friction loss equation, the larger the number; the less resistance associated with the pipe's surface and friction loss is reduced. Table 3.7 lists the friction coefficients found in many hydraulic texts (Ross). For example, the flexible hose has the highest friction coefficient which means it has the smoothest surface and will provide the lowest friction loss holding all other parameters constant.

Table 3.7. Friction Coefficient Indices

Composition of Pipe			
PVC	Aluminum	Flexible Hose	Steel
150	120	180	120

The following form of the Hazen-Williams friction loss equation for flow in circular pipes found in many hydraulic texts is used to determine the friction loss on a per foot Basis (Ross). Equation 3.21 specifies this calculation using the main pipe as an example. The Hazen-Williams principal is used with the different pipe sections, except for the pipe containing multi-sprinkler systems. The multi-sprinkler systems have a factor that reduces friction loss to account for the fact that water volume is reduced as it flows past a sprinkler.

$$HFM=((2.3*V3)/((1.318*CF(TOP2))*((SD1/12)^{.63})))^{1.852} \quad (3.21)$$

where:

HFM = Friction loss in main pipe on a per foot BASIS
V3 = Velocity of water in main pipe
TOP2 = Type of pipe; and
CF = Friction coefficient.

For the center pivot system a factor of 0.33 is used to account for the reduced water volume as water moves past and through sprinklers in its journey through the center pivot arm. With the portable pipe and fixed big gun the factor is dependent on the number of sprinklers or guns. If only one gun is present the factor is 1.0, with two guns the factor

is 0.50, and with three or more guns the factor is 0.33 (Ross). For example, if two guns are present on a fixed big gun system, the value for HFL would be multiplied by 0.5 to determine the per foot friction loss from the lateral pipe.

3.7.3 Calculating Horsepower Requirements

Before horsepower could be calculated, all friction loss values and lift had to be translated into total head (TH) where head equals the energy needed to lift a column of water one foot (Ross). The Hazen-Williams principal calculates friction loss on a per foot basis, so the friction loss calculations must be multiplied by their respective lengths to calculate the total loss of energy in feet. Added to the friction loss figure is the total feet the water must be lifted by the system or the vertical distance from the water source's level to the highest sprinkler in the system. The operating pressure of sprinklers is defined to be 70 pounds per square inch for the center pivot system, 75 pounds per square inch for fixed big gun, and 50 pounds per square inch for the portable pipe system. The pressure at the nozzel of the traveling gun system ranges from 75 to 95 pounds per square inch depending on the gallons per minute capacity of the system. These different operating pressure values are multiplied by 2.31 to determine the lift required to move the water through the irrigation system at these pressures (Ross). Finally, all values are summed to determine the total head required to move the water through the system and meet all the requirements discussed above for each situation.

Once total head is calculated, there is a calculation that transforms total head and

gallons per minute into horsepower requirements. This calculation is specified in equation 3.22.

$$HP\% = ((TH * GPM)/(3960 * 0.8)) + 0.5 \qquad (3.22)$$

where:

HP%	=	Horsepower requirements rounded up to an integer;
TH	=	Total head of system;
GPM	=	Gallons per minute; and
0.8	=	Factor showing the energy efficiency of a diesel engine.

3.8 Annual Variable Cost

Annual variable costs of irrigation include all the cost variables that can be controlled during the season. These costs are a significant part of the total system cost and they vary by the type of system being used. Energy, lubrication, maintenance, labor cost, cost of additional inputs, and lost production are the items that account for the total annual variable cost.

3.8.1 Operating Expenses

One of the more important variables influencing the operating expenses for any irrigation system is the number of days the system is operating over the growing season. The number of drought days for any given year is randomly selected from the range defined previously by Table 3.3. The system is assumed to be operating on those days the field is experiencing a drought day and the more drought days experienced, the higher the irrigation cost.

Another important factor affecting operating cost is the size of the engine or amount of horsepower required to pump the water. The more horsepower; the more energy is needed, ceterus paribus. Combining horsepower with operating time produces horsepower-hours. Horsepower-hours is the variable that drives the cost related to the operation of the systems. The following equation specifies the calculation for annual horsepower-hours for a traveling gun system and this logic holds for all design models.

$$HPHR = HP\% * TPR * NUMR * CPS \qquad (3.23)$$

where:

HPHR = Annual horsepower-hours;
HP% = Horsepower requirements of system;
TPR = Number of hours per irrigation run;
NUMR = Number of runs per irrigation cycle; and
CPS = Annual number of irrigation cycles per season.

Fuel consumption, oil consumption, and repair and maintenance cost are directly related to horsepower-hours. Table 3.8 lists the factors used to compute these items for a diesel power unit (Turner, et al). Multiplying the factors in Table 3.8 by horsepower-hours, fuel and oil consumption, and annual maintenance costs are computed.

Table 3.8. Relating Operating Cost to Brakehorsepower-Hours

	FACTOR
Horsepower-hours per gallon of Diesel Fuel....	14.6
Horsepower-hours per gallon of Oil.....	3000.0
Maintenance Cost per Horsepower-hour.....	$0.0019

3.8.2 Labor Cost

Labor hours have been discussed in earlier sections, because each calculation is system dependent. Here in Table 3.9 all items associated with labor cost are summarized below (Turner, et al.).

Table 3.9. Labor Time Assumptions for the Systems in Minutes

SYSTEM	Per TRIP	Per ACRE	Per DAY	Per Cycle	# OF PEOPLE
PORTABLE PIPE	30	60	0	0	4
BIG FIXED GUN	30	45	0	0	4
TRAVELING GUN	30	12	0	0	1
CENTER PIVOT	30	0	30	60	1

On a per acre basis, Table 3.9 details the obvious labor savings the traveling gun has over the portable pipe and fixed big gun. The labor savings associated with the center pivot system are relatively large compared to the other systems. With labor-hours calculated, labor cost per season is calculated by multiplying labor-hours by the hourly wage rate.

3.8.3 Cost of Lost Production due to Irrigation

Irrigation systems require space to operate. These requirements change by type of system. Table 3.10 lists the acres of productive land lost per irrigated acre for each

system (Turner, et al.). For example, for every acre irrigated by a portable pipe system, one percent of the productive land will not produce any corn, because the system occupies this lost land.

Table 3.10. Lost Productive Acres per Acre Irrigated

Type of System	Acres Lost per Acre Irrigated
Portable Pipe	0.01
Big Fixed Gun	0.01
Traveling Gun	0.04
Center Pivot	0.02

The cost of this lost production is based on the yields produced without irrigation. Using the information in Table 3.10, the yield information in Table 3.1, and the price of corn, the total cost from lost production is calculated. Equation 3.24 details this calculation.

$$COLP = YPA * CROPPC * AACRE * FACTOR \quad (3.24)$$

where:

COLP = Cost of lost production (dollars per acre);
YPA(I) = Yield per acre associated with soil I (Bu./Ac.);
CROPPC = Price of corn (dollars per bushel);
AACRE = Total acres irrigated; and
FACTOR = Factor from table 3.10 for each system.

3.9 Calculating Annual Fixed Cost

The dimensions of the system have been calculated, the various components of the system have been counted, and the cost of these various items can now be summed. The

cost per unit of these components are obtained through irrigation product catalogs and Virginia based irrigation dealers and are in 1983 dollars (Booth, Spillman, Newcomb, Brantley).

These components can be grouped into 4 broad categories as follows:

1) pipe,
2) riser and sprinklers,
3) pipe fittings and hook-ups, and
4) pumps and generators.

3.9.1 Cost of Pipe

The pipe components can be organized as main, submain, and lateral. The types of pipe included pvc, aluminum, steel, and flexible hose. The main pipe for all systems is buried pvc pipe. The submain and lateral for the portable pipe and fixed big gun systems are aluminum. Since the length of pipe has already been defined in the program and the diameter of the pipe has been defined, a matrix is used in the design programs so that the correct pipe price can be selected. Table 3.11 lists the prices used in the design models (Ross). A 2-inch diameter aluminum pipe would cost $1.29 per foot.

Center pivot systems are specially designed to carry large volumes of water and only one pipe runs the radius of the field creating a direct relationship between length of arm and water volume. As these systems get longer the support structure must grow and cost per foot escalates. Table 3.12 details the per foot price based on the length of the arm (Ross). For example, a center pivot arm that has a length of 1,505 feet would cost $32.00 per foot for a total cost of $48,160.

Table 3.11. Cost of Aluminum and Buried PVC pipe on a per Foot Basis

Diameter of Pipe (in.)	Cost per Foot	
	Aluminum Pipe	Buried PVC Pipe
2	$1.29	$1.50
3	$1.77	$2.00
4	$2.27	$2.50
5	$2.89	$3.00
6	$3.86	$3.00
7	$5.73	$4.25
8	$7.15	$4.25

Table 3.12. Relationship between the Cost of Center Pivot Arm and its Length

Length of Center Pivot Arm	Cost of Arm per Foot
less than 1,445 feet	$28.00
1,446 - 1,560 feet	$32.00
1,561 - 1,900 feet	$34.00
1,901 - 2,040 feet	$37.00

With the traveling gun system, the main pipe went from the water source across the width of the field to the last run from the water source. The traveling gun is a specialized irrigation system that is designed to operate under high pressure. The higher the water flow; the higher the cost of hose, reel, and traveler. The relationship is linear

and $40 multiplied by the number of gallons per minute flowing through the system equals the cost of the hose, reel, and traveler in this model (Ross).

3.9.2 Cost of Risers and Sprinklers

Risers and sprinklers are used specifically with the portable pipe and fixed big gun systems. The riser rises from the lateral pipe to get the sprinkler in the air, and the sprinkler is attached to the top to disperse the water. Table 3.13 lists the unit prices that are multiplied by the number of risers and sprinklers to calculate their total cost (Ross). For example, risers and sprinklers for a portable pipe system cost $35.00 each.

Table 3.13. Unit Prices of Risers and Sprinklers

Type of System	Unit Price
Portable Pipe	$ 35.00
Fixed Big Gun	$800.00

3.9.3 Cost of Pipe Fittings and Hook-ups

Where the lateral pipe or flexible hose makes its connection to the pipe there is a need for a t-valve or hydrant, respectively. These are special components needed to connect the pipes that also can handle the water pressure without leaking. Once the number of these components are computed, they can be multiplied by their respective unit prices found in Table 3.14 to calculate their total cost (Ross).

Table 3.14. Cost of T-valves and Hydrants

Diameter of Pipe (in.)	Unit Price of Components		
	Portable Pipe	Fixed Big Gun	Traveling Gun
2	$120.00	$120.00	$20.00
3	$120.00	$120.00	$30.00
4	$140.00	$140.00	$40.00
5	$140.00	$140.00	$50.00
6	$140.00	$140.00	$60.00
7	$140.00	$140.00	$70.00
8	$140.00	$140.00	$80.00

For the center pivot system, there is only one point where the lateral (center pivot arm) meets the main pipe. At this point, the arm needs support. This support is given by a cement pad which costs $500.00 for any size center pivot system (Ross).

3.9.4 Cost of Power Units and Pumps

The cost of the pump and power unit is assumed to be a linear relationship based on the horsepower size of the power unit. To determine the impact the cost of horsepower will have on the overall cost of the system, the cost per horsepower is a uniform random variable between $125 and $225 in the design program. The total cost of the power unit is calculated by multiplying this per unit horsepower cost by the total horsepower of the power unit.

With the center pivot system, another power unit is needed to generate electricity to

drive the powertrain that moves the center pivot's arm. A linear relationship is used which stated that each foot of the center pivot's arm would add $7.00 to the cost of the center pivot system. Therefore, the total cost of the power unit to drive the powertrain is calculated by multiplying $7.00 by the arm's length (Ross).

3.9.5 Annualizing the Investment Cost

For the purposes of this study, investment cost is capitalized over the life of the system which is 15 years for all systems. The resale value for all systems is assumed to be zero to keep the analysis as objective as possible. This salvage value assumption will make the cost estimates higher relative to real world situations, but salvage value is situation dependent value and is felt to be insignificant for this research. With these assumptions, the cost of the system is amortized over the system's life by using the standard capital recovery equation shown below (Taylor, et al.):

$$CRF = IR/\{1 - (1+IR)^{-L}\} \qquad (3.25)$$

where:

CRF = capital recovery factor;
IR = interest rate; and
L = life of system (all systems had a 15 year life).

To determine the amount of money being expensed every year, the capital recovery factor had to be multiplied by total investment cost as shown in equation 3.26:

$$AIC = INVES * CRF \qquad (3.26)$$

where:

AIC = annualized investment cost;
INVES = total investment cost; and
CRF = capital recovery factor.

3.9.6 Cost of Insurance and Taxes

Taxes are a fixed cost, because annual taxes are paid once this system is purchased. An assumption that farmers are risk averse is used and insurance cost is also assumed to be a fixed cost. Two percent of the total investment cost is used to estimate the annual cost of taxes and insurance (Ross). Income taxes are not addressed in the design model as they are also impacted by the revenue stream and can not be addressed only from the cost perspective.

3.10 Total Annualized Cost of Irrigation

All the annual variable cost factors are added to the annualized fixed cost to calculate the total annual irrigation cost. Since the econometric models will use the annual fixed, variable, and total cost on a per acre basis each of these cost variables are divided by the actual acres irrigated to calculate the annual per acre cost of irrigation.

CHAPTER 4

Econometric Models

The design models are site specific models and cumbersome to use. They require a microcomputer, details from each site must be entered into the program, and the time needed to analyze the state of Virginia with a site specific model is prohibitive. To overcome the design models' shortcomings, econometric equations are created. These econometric models summarize the design models' information and make reasonably accurate irrigation cost projections. The econometric models will save time in determining the field locations which are potential irrigation sites across the state of Virginia. The time savings in this analysis more than compensates for the lower accuracy of the econometric models relative to the design models.

The first step in this cost equation development process is to build a database of site specific information with the design models. Next, the appropriate statistical procedure is selected to estimate the equations. Lastly, using the selected statistical procedure, the variables that significantly contributed to the cost estimates are selected and parameter estimates calculated for average annual per acre fixed, variable, and total cost.

4.1 Building the Dataset for Analysis

The dataset should represent all possible sites and environmental cases covered by the design models. To achieve this, most variables that influenced cost are randomized within

a specified range. One must note, the econometric equations generated by this analysis can only be used to predict cost over the ranges used to estimate the parameters. For example, acres irrigated by the traveling gun is simulated between 10 and 110 acres, so the econometric equation for the traveling gun system would yield a statistically valid cost estimate for a site with a field size within this range. The parameter list and the ranges are listed in Table 4.1.

Table 4.1. Ranges Simulated by Design Models

Number of Operating Days (days)	
....for high water holding soil.....	1 - 88
....for medium water holding soil.....	1 - 103
....for low water holding soil.....	1 - 123
Acres Irrigated by each System (acres)	
....portable pipe.....	1 - 80
....big fixed gun.....	1 - 80
....traveling gun.....	10 - 110
....center pivot.....	30 - 300
Hours each System will Operate each Day (hours)	
....portable pipe.....	less than or equal to 18
....big fixed gun.....	less than or equal to 18
....traveling gun.....	18 - 23
....center pivot.....	24
Horizontal Distance from Water Source (feet).....	50 - 15,804
Vertical Distance Water is Pumped from Source (feet)..	5 - 300
Cost of Fuel (dollars per gallon).....	$0.75 - $1.50
Cost of Engine per Horsepower (dollars).....	$125 - $225
Cost of Capital (interest rate).....	5.0% - 25.0%
Corn's Peak Consumptive Use of Water (inches per day).	0.2 - 0.25
Selling Price of Corn (dollars per bushel).....	$1.39 - $5.56
Labor Wage Rate (dollars per hour).....	$3.35 - $6.70

All of these variables and their ranges are discussed in Chapter 3. By randomly selecting a number for each parameter within its range and simulating each parameter set through the design model, costs are generated based on specific agronomic, economic, meteorological, and environmental conditions. A database of 3,000 observations per system is created which will be used to build the econometric equations. This database is created by running each design model 1,000 times for each of the three different moisture holding soils. With this routine, a database with 12,000 observations is created for the four different irrigation systems.

The database is created by simulating the design models. BASIC is the program used and the random number generator within BASIC is used to create a uniform distribution of observations within the defined ranges and independence is assumed between all the variables. Since this database has been produced by the design models, which are also a mathematical creation, the relationships between the variables and cost are known a prori. Therefore, the statistical equations being tested are not being selected for their significance, but for there relative impact on cost. Since the goal of these econometric models is to save time and simplify the analytical process, significant variables could be dropped if the econometric models lose little explanatory power.

4.2 Selecting the Statistical Model

Total cost is the sum of fixed and variable cost. Some of the exogenous variables have an impact on fixed cost and some have an impact on variable cost. To improve the

accuracy of the parameter estimates and improve the overall accuracy of the total cost estimates, the cost components are each estimated separately, creating three equations. Before an estimation procedure could be identified, the type of relationships between these cost components and the exogenous variables had to be assessed.

Preliminary analysis of the dataset suggested a linear relationship existed between average fixed, variable, and total per acre cost of irrigation and each independent variable, except for the relationship between average fixed per acre cost and field size. Average per acre fixed cost dropped quickly as field size increased and then its magnitude leveled out as additional acres are added.

This rapid reduction in per acre costs, as acres initially increased, is logical, because the percentage change in acres is larger than percentage change in fixed cost. At the other extreme as the field size becomes large, an additional acre will have an insignificant impact on average fixed cost per acre, because the percentage change in acres is insignificant. For example, going from 1 acre to 2 acres doubles the operation size and potentially halves the fixed cost per acre, but going from 100 acres to 101 acres increases the size of operation by 1.0 percent and potentially provides a 1.0 percent decrease in fixed cost per acre, assuming no additional fixed cost is required for the additional acres. Therefore, the variable violated the linear assumption.

To create a linear model, the relationship between average per acre fixed cost and field size had to be transformed from a nonlinear to a linear relationship. This linear transformation is accomplished by taking acres and using its inverse. Using the same

hypothetical situation above, going from 1 acre to 2 acres causes 1/acre to go from 1 to 0.5 where going from 100 acres to 101 acres causes 1/acre to go from 0.01 to 0.009901. The 1/acre variable changes dramatically when acres are small and almost insignificantly when acres are large, which counterbalances the impact acre has on per acre cost. Using the inverse of acres, a linear relationship between fixed cost and field size is created.

Since a linear relationship between fixed cost, variable cost, and total cost are known to exist, a linear estimation procedure is used to analyze the dataset. Ordinary least squares (OLS) and three stage least squares (3SLS) are determined to be the best estimation procedures. OLS treats each equation independently and estimates the best equation for each cost component by minimizing the squared difference between the actual cost and the estimated cost versus 3SLS which would minimize the squared difference between the actual cost and estimated cost for a system of equations.

First, OLS is used to estimate the equation for each cost component. Tests for serial correlation, t-tests and tests for multicollinearity are used to create the best model. Next, 3SLS is run on the equations as a system of equations. Finally, a t-test of the parameter estimates produced by OLS and 3SLS is used to test for statistically significant differences between the two. If no difference is found, OLS would be used; and 3SLS would be used if differences are found.

4.3 Variable Selection of the Fixed Cost Equations with OLS

The potential variables for the per acre fixed cost equations are summarized in Table 4.2. All of these variables have an impact on fixed cost as they affect the amount of pipe, or the amount and cost of horsepower required to deliver the water to meet the crop's needs. For example, horizontal distance (HD) impacts fixed cost by requiring a larger pump and more horsepower to move water through a pipe as distance increases.

All variables are explained in Chapter 3, except for SD. The variable, SD, represents the different water holding capacity soils. Since these soils have different water holding capacities, they require different amounts of water which must be irrigated to restore the soil water. Larger volumes of water requires different irrigation designs. Therefore, the hypothesis, that different water holding capacity soils would significantly impact fixed cost is tested by this model.

Table 4.2. Potential Variables for Fixed Cost Equation

portable pipe	big fixed gun	traveling gun	center pivot
1/acre	1/acre	1/acre	1/acre
HD	HD	HD	HD
IR	IR	IR	IR
CHP	CHP	CHP	CHP
VDD	VD	VD	VD
CU	CU	CU	CU
HOURS	HOURS	HOURS	HOURS
SD	SD	SD	SD

With the average per acre fixed cost equations, signs of the parameter estimates, t-tests, adjusted R squares, and a desire to keep the equations as similar as possible are factors that determined the parameters selected for each equation. Table 4.3 lists the variables that are eliminated from the fixed cost equation, along with the reasons for their elimination.

Table 4.3. Insignificant Variables in Fixed Cost Equation

	Reason Parameter Failed			
Parameter that Failed	portable pipe	big fixed gun	traveling gun	center pivot
CHP	t-test[a]	t-test[a]	significant[b]	significant[b]
VD	t-test[a]	t-test[a]	R-squared [c]	R-squared [c]
CU	t-test[a]	t-test[a]	R-squared [c]	R-squared[c]
HOURS	t-test[a]	wrong sign[d]	R-squared [c]	wrong sign[d]
SD	t-test[a]	R-squared [c]	R-squared [c]	t-test [a]

[a] the variable is not significantly different from zero.
[b] variable is significant in these equations.
[c] variable is significant in this equation, but their explanatory. contribution to equation is determined to be insignificant.
[d] the sign for the variable is inconsistent with theory.

The only variable, that is included in some equations and not in others, is CHP, because the variable contributes significantly to the explanatory power of the equation and theory supports this difference. With the smaller systems, portable pipe and big fixed gun, smaller plots of land are irrigated at one time versus the larger systems, traveling

gun and center pivot, that irrigate large plots of land at one time. This relationship means pump size for the smaller systems will be smaller relative to the larger systems, the horsepower requirement will be smaller, and the cost of horsepower, CHP, has an insignificant impact on the total fixed cost of the smaller systems, but is significant in the larger systems. Based on this logic, CHP was deleted from the portable pipe and big fixed gun models while CHP was incorporated into the traveling gun and center pivot models.

The elimination of variables from the portable pipe model is straight forward as all variables deleted from the equation are not significant. The probability that the variable equalled zero had to be lower than .001 before the variable could be classified as significant. This stringent test is used because of the large sample size of 3,000 observations per equation.

The elimination of the variable, HOURS, from the traveling gun, where it is a statistically significant variable, is based on the reasoning that if capital can be substituted for labor at a cost savings, which is what the variable HOURS is testing, then this savings should be greatest with the labor intensive systems, portable pipe and fixed big gun, where they were actually insignificant. Since the variable is insignificant in the labor intensive systems, this variable is deleted from the capital intensive system.

The elimination of the varible, SD, from the fixed big gun and center pivot equations is based on the reasoning that this variable had the same impact on fixed cost in all the design models and the variable is insignificant in the portable pipe equation and

significant in the fixed big gun equation. Since these two design models are so similar, no logic supports this finding and the variable is deleted from all the equations.

For the variables, VD and CU, these variables are deleted because their contribution to explaining the variation in fixed cost is considered to be relatively insignificant. The explained variation from the mean divided by total variation from the mean is the definition of R-squared. More formally, explained variation is the estimated observation subtracted from the mean of the sample, squaring each value, and summing these values. The total variation is the summed squares of the actual observations subtracted from the mean of the sample. When the explained variation is divided by total variation, a goodness of fit is calculated and the closer the calculated number is to one the better the fit (Pindyck and Rubinfeld).

R-squared can be increased by increasing the number of parameters in the equation as adding a variable to the equation will never cause the explained variation to fall. Adjusted R-squared is a better goodness of fit indicator, as adjusted R-squared can decrease if an additional variable is added. Adjusted R-squared is unexplained variation divided by total variation subtracted from one. Unexplained variation is the sum of the squared error terms divided by their degrees of freedom and the total variation is the sample variation divided by its degrees of freedom (Pindyck and Rubinfeld).

R-squared is used as a reason to delete a variable from an equation when very little information is lost through this deletion. Since little information is lost, increased confidence can be placed in the equations, because of the similar logic used in the design

models. The one difference in the design models which could logically support different variables in the econometric equations is the fact that the portable pipe and fixed big gun models are more labor intensive systems than the traveling gun and center pivot systems. This is why the variable CHP is in the capital intensive systems, but deleted from the labor intensive systems.

Table 4.4 shows the adjusted R-squared when all variables are present versus the adjusted R-squared of the models when only the consistent and significant variables are present.

Table 4.4. Comparing Adjusted R Squared[a]

	Fixed Gun	Traveling Gun	Center Pivot
With all Parameters	0.7744	0.8692	0.9276
Only Consistent and Significant Variables	0.7723	0.8409	0.9192
Difference	0.0021	0.0283	0.0084

[a] portable pipe equation is not shown because all variable deleted were deleted because they are statistically insignificant from zero.

The traveling gun model looses the most explanatory power as the adjusted R-squared fell from 86.92 percent to 84.09 percent causing the goodness of fit to fall 2.83 percent. However, the traveling gun model still outperforms the fixed gun model and the lost explanatory power of the model is deemed to be justified by the consistency and

simplicity that is gained by deleting these variables from the equations.

4.4 Variable Selection of the Variable Cost Equations with OLS

The potential variables for the per acre variable cost equations are summarized in Table 4.5. All of these variables are thought to have an impact on variable cost via impacting energy consumption, opportunity cost of lost output, and labor cost. For example, number of drought days (NOD) impacts the amount of time the system will operate each year as energy consumption will increase when the number of drought days increases which will cause variable cost to rise.

Table 4.5. Potential Variables in Variable Cost Equation

portable pipe	big fixed gun	traveling gun	center pivot
VD	VD	VD	VD
NOD	NOD	NOD	NOD
CE	CE	CE	CE
CU	CU	CU	CU
CROPPC	CROPPC	CROPPC	CROPPC
WAGERT	WAGERT	WAGERT	WAGERT
SD	SD	SD	SD

The logic supporting the variables contributing to per acre variable costs is listed in Table 4.6. Table 4.6 lists how per acre variable cost is impacted when each variable is increased.

Table 4.6. Reasons Why Variables have Impact on Variable Cost

VD.....	Increases work load increasing energy consumption
NOD.....	Increases operating time increasing energy consumption
CE.....	Increases cost of energy
CU.....	Increases water volume increasing energy consumption
CROPPC...	Increases opportunity cost of lost land
WAGERT...	Increases labor cost
SD.....	As soil's water holding capacity increases, reduces water volume and reduces input requirements decreasing energy consumption

With the average per acre variable cost equations, signs of the parameter estimates, t-tests, adjusted R-squares, multicollinearity tests and a desire to keep the equations similar were factors that determined the parameters selected for each equation. Table 4.7 lists the only eliminated variable, consumptive use (CU), and the reason why it is eliminated from the equations.

Table 4.7. Insignificant Variables in Variable Cost Equation

	Reason Parameter Failed			
Parameter that Failed	portable pipe	big fixed gun	traveling gun	center pivot
CU	collinearity[a]	collinearity[a]	collinearity[a]	collinearity[a]

[a] the variable is dropped because it is highly related to other explanatory variable

The analysis of the OLS equations when all potential variables are present revealed a problem with collinearity as the condition indices for all equations are larger than 60. Typically, a condition index above 30 is a strong indication that collinearity exists. Since the condition index is greater than 60, collinearity had to be corrected before the parameter estimates could be considered accurate.

Collinearity is created when a high correlation exists between the explanatory variables. This correlation could be a correlation between two variables or a linear correlation between a multiple of variables (Pindyk and Rubinfeld). A solution to the collinearity problem corrects for this correlation between explanatory variables. The solution used in this thesis is to determine the variables which had a high correlation by examining the eigenvalues. Once the variables are identified, these variables would be deleted until the collinearity problem is corrected.

The condition index and the less than 30 rule is the test used to determine if collinearity is corrected. Singular value decomposition dissects the total variance of the regression estimator into its various parts and this analytical tool is used to determine which explanatory variables are correlated. The portable pipe model is used as an example to explain the process, but the same pattern is observed in the other models.

First, the condition index is 60.8. The eighth eigenvalue is associated with 96.2 percent of the total variation of the regression intercept and 91.6 percent of the total variation of the regression estimator associated with the CU variable. This is a strong indication that these two explanatory variables are highly correlated. When the CU

variable is deleted from the model, condition indices are reduced below 30 for all models showing this variable is involved in the collinearity problem. Table 4.8 lists the condition index for each model with and without the CU variable.

Table 4.8. Condition Index for Variable Cost Models

	Portable Pipe	Big Fixed Gun	Traveling Gun	Center Pivot
With "CU"	60.8	60.8	61.4	60.7
Without "CU"	23.9	23.9	23.2	23.8

4.5 Ordinary Least Squares versus Three Stage Least Squares

The next stage involves selecting the estimation procedure which will yield the best outcome. The two procedures tested are ordinary least squares (OLS) and three stage least squares (3SLS). If possible, OLS is the method of choice, because it simplifies the interpretation of the results as it treats each equation within the model as independent. On the other hand, 3SLS treats each equation within the model as being interdependent and uses this information to increase the accuracy of its estimates.

The model that is being estimated is shown below in Equations 4.1 through 4.3. As stated earlier, each variable listed in these equations has been shown to be significant through the analysis in Sections 4.3 and 4.4.

Equation 4.1 contains the variable, CHP, for the traveling gun and center pivot models, but this variable is absent from the portable pipe and big fixed gun models. All the other variables are consistent across all irrigation models.

$$AFCPA = \beta_0+\beta_1(1/ACE)+\beta_2(HD)+\beta_3(IR)+\beta_5(CHP) \quad (4.1)$$

$$AVCPA = \beta_6+\beta_7(VD)+\beta_8(NOD)+\beta_9(CE)+\beta_{10}(CROPPC)2+\beta_{11}(WAGERT)+\beta_{12}(SD) \quad (4.2)$$

$$ATCPA = AFCPA + AVCPA \quad (4.3)$$

where:

β_i, for i = 1 to 12,	= parameter estimates for each variable;
AFCPA	= average fixed cost per acre;
1/ACRE	= inverse of acreage covered by irrigation system;
HD	= distance from edge of water source to edge of field;
IR	= interest rate used for capital recovery calculations;
CHP	= cost of power plant on a horsepower basis;
AVCPA	= annual variable cost per acre;
VD	= distance from water surface to highest point on system;
NOD	= number of days system will be operating each year;
CE	= cost of diesel fuel per gallon;
CROPPC	= selling price for corn;
WAGERT	= labor wage rate per hour;
SD	= Water holding capacity of soil; and
ATCPA	= average total cost per acre.

The criteria, used to select the estimation technique, is to test for significant differences between the OLS and 3SLS calculations of the parameter estimates for each variable. If any parameter estimates are different, 3SLS would be the technique chosen.

The portable pipe model is presented as the best example to demonstrate how the hypothesis that no difference existed between the parameter estimates created by the two techniques is tested. Since the portable pipe model had the largest variance, parameter

estimates would have the largest difference; thus the most severe test.

Table 4.9 lists the parameter estimates for both OLS, and 3SLS estimation procedures; and lists the t-test statistic for comparison across regression techniques for each variable in the portable pipe model.

Table 4.9. Comparing OLS and 3SLS Parameter Estimates

Equation	Variable	OLS Parameter Estimate	3SLS Parameter Estimate	t-statistic
Fixed Cost	Intercept	-288.48	-288.75	0.019
Fixed Cost	1/Acre	3176.46	3177.07	-0.018
Fixed Cost	HD	0.02709	0.02711	-0.019
Fixed Cost	IR	1161.49	1162.08	-0.008
Variable Cost	Intercept	-95.58	-95.57	-0.003
Variable Cost	VD	0.1973	0.1973	-0.001
Variable Cost	NOD	1.9858	1.9857	0.005
Variable Cost	CE	57.08	57.06	0.011
Variable Cost	WAGERT	7.9385	7.9393	-0.002
Variable Cost	CROPPC	0.6385	0.6416	-0.010
Variable Cost	SD	37.90	37.91	-0.004

The t-test is used to test the hypothesis that the parameter estimates created by the OLS and 3SLS are equivalent. Since each parameter estimate had 3,000 observations and a type II error was determined to be more acceptable, a ninety percent confidence level was used to test this hypothesis. The degrees of freedom for all t-tests in the fixed cost

equation are 2,996 and 2,993 in the variable cost equation. Using a two-tailed test, at the 90 percent confidence level, and with 2,996 or 2,993 degrees of freedom, the critical value equals 1.645 (Li, et al).

The highest absolute t-value calculated is 0.019 which is below the critical value of 1.645. The hypothesis that all parameter estimates for the portable pipe model are equal using the OLS or 3SLS method is accepted. Therefore, the OLS model gives the same values as the more sophisticated 3SLS procedure and OLS is selected as the procedure of choice to estimate all models.

4.6 Parameters and Equation Diagnostics for Fixed Cost Equations

As stated above, the functional form is a linear model where the fixed cost and variable cost equations are considered to be independent. The focus in this section will be on the fixed cost equation using estimates from the OLS procedure. The basic form for the fixed cost equation follows in Equation 4.4.

$$AFCPA = ß_0 + ß_1(1/ACRE) + ß_2(HD) + ß_3(IR) + ß_5(CHP) \qquad (4.4)$$

where:

$ß_0, ß_1, ß_2, ß_3, ß_4, ß_5$	= parameters estimated by OLS;
AFCPA	= average fixed cost per acre;
1/ACRE	= inverse of acreage covered by irrigation system;
HD	= distance from edge of water source to edge of field;
IR	= interest rate used for capital recovery calculations; and
CHP	= cost of power plant on a horsepower basis.

As stated earlier, CHP is insignificant in the portable pipe and big fixed gun equations and it is not included in these models. The following tables give the parameter

estimate, standard error, probability that parameter estimate equals zero based on t statistic, the equation's F-statistic, the equation's adjusted R-squared, and the number of observations used to create these statistics for each irrigation system.

Table 4.10. Statistics for Annual Fixed Cost Equation For Portable Pipe System

Parameter	Standard Estimate	Probability Error	> |T|
INTERCEPT	-288.48	14.26667	0.0001
1/ACRE	3,176.46	34.60685	0.0001
HD	0.02709	0.00095	0.0001
IR	1,161.49	74.83451	0.0001

ADDITIONAL DIAGNOSTICS:
F = 3,166.65; ADJUSTED R-SQUARED = .76
NUMBER OF OBSERVATIONS = 3,000

Using the center pivot equation as an example, the interpretation of these equations is shown using the data in Table 4.14. The estimated annual fixed cost per acre is $101.69 or multiplying by 100 acres, the estimated annual fixed cost for this system is $10,169.00. This is an estimate of cost that must be paid annually whether the center pivot system is used or not.

By taking the partial derivative of this equation with respect to a variable, the marginal impact on the annual per acre fixed cost of a small change in the variable can be derived. Excluding the acre variable, the first partial derivative of all the other

Table 4.11. Statistics for Annual Fixed Cost Equation For Fixed Big Gun System

Parameter Estimate	Standard Error	Probability > |T|	
INTERCEPT	-350.45	17.62808	0.0001
1/ACRE	4,120.51	42.75970	0.0001
HD	0.02991	0.00117	0.0001
IR	1,360.23	92.46653	0.0001

ADDITIONAL DIAGNOSTICS:
F = 3,392.28; ADJUSTED R-SQUARED = .7723
NUMBER OF OBSERVATIONS = 3,000

Table 4.12. Statistics for Annual Fixed Cost Equation For Traveling Gun System

Parameter Estimate	Standard Error	Probability > |T|	
INTERCEPT	-109.75	4.93076	0.0001
1/ACRE	2,231.37	36.87234	0.0001
HD	0.0137	0.00016	0.0001
IR	870.78	12.30576	0.0001
CHP	0.1393	0.02440	0.0001

ADDITIONAL DIAGNOSTICS:
F = 3,962.75; ADJUSTED R-SQUARED = .8409
NUMBER OF OBSERVATIONS = 3,000

Table 4.13. Statistics for Annual Fixed Cost Equation For Center Pivot System

Parameter Estimate	Standard Error	Probability > |T|	
INTERCEPT	- 69.90	2.43702	0.0001
1/ACRE	6,428.13	56.17963	0.0001
HD	0.00703	0.00008	0.0001
IR	688.02	6.04264	0.0001
CHP	0.09521	0.01213	0.0001

ADDITIONAL DIAGNOSTICS:
F = 8,528.06; ADJUSTED R-SQUARED = .9192
NUMBER OF OBSERVATIONS = 3,000

Table 4.14. Example of Using the Center Pivot Fixed Cost Equation

Site Variable	Parameter Data	Estimate	Value
Intercept	1	- 69.90	-$ 69.90
Acre	100	6,428.13	$ 62.88
HD	1000	0.00703	$ 7.03
IR	0.125	688.02	$ 86.00
CHP	150	0.09521	$ 14.28
			=====
Total Per Acre Fixed Cost =			$ 101.69

variables yields a constant equal to the parameter estimate. Therefore, moving from 1,000 feet to 2,000 feet from the water source would add another $7.03 to the annual per acre fixed cost of $101.69 resulting in a cost of $108.72.

To calculate the marginal impact on annual fixed cost with a small change in acres, the partial derivative is listed in Equation 4.5.

$$\text{Marginal impact on fixed cost} = -6376.86(\text{ACRE})^{-2} \qquad (4.5)$$

As Equation 4.5 shows, a change in acreage does not yield a constant impact on cost. In fact, the Equation 4.5 only yields an accurate estimate at a specific acreage size and the further one moves from that acreage, the less accurate the estimate will be. Table 4.15 shows the expected change in cost at specific acreages and how this change decreases as size of field is increased.

Table 4.15 shows that as acreage gets larger, its impact on cost gets smaller. For example, going from 30 acres to 31 acres would reduce the per acre fixed cost by an estimated $7.09. However, this estimate would be upwardly biased, because the impact is constantly changing as the acreage is changing. In fact, at 31 acres the change is a reduction of $6.64 per acre at the margin, so the actual impact of increasing acreage from 30 to 31 acres would be a reduction of between $6.64 and $7.09 per acre. This is more complicated than the constant change found with the other variables, but with some quick calculations some useful information can be ascertained.

Table 4.15. Change in Fixed Cost Expected as Acres Change

ACRES	Expected Change in Per Acre Fixed Cost for Various Field Sizes
30	- $7.09
40	- $3.99
50	- $2.55
100	- $0.64
150	- $0.28
200	- $0.16
300	- $0.07

4.7 Equation Diagnostics for Variable Cost Equations

This section is concerned with the variable cost equation of this model. The basic form of the variable cost equation follows:

$$AVCPA = \beta_0+\beta_1(VD)+\beta_2(NOD)+\beta_3(CE)+\beta_4(CROPPC)+\beta_5(WAGERT)+\beta_6(SD) \quad (4.6)$$

where:

β_0, β_1, β_2, β_3, β_4, β_5, and β_6 = parameters estimated by OLS;
AVCPA = annual variable cost per acre;
VD = distance from water surface to highest point on system;
NOD = number of days system will be operating each year;
CE = cost of diesel fuel per gallon;
CROPPC = selling price for corn;
WAGERT = labor wage rate per hour; and
SD = Water holding capacity of soil.

The following tables give the parameter estimate, standard error, probability that a parameter estimate equals zero based on its t- statistic, F statistic for the equation, and adjusted R-squared for the equation.

Table 4.16. Statistics for Annual Variable Cost Equation For Portable Pipe System

	Parameter Estimate	Standard Error	Probability > |T|
INTERCEPT	-95.58	3.20934	0.0001
VD	0.1973	0.00456	0.0001
NOD	1.9858	0.01259	0.0001
CE	57.083	1.80683	0.0001
WAGERT	7.9385	0.39400	0.0001
CROPPC	0.6385	0.31435	0.0423
SD	37.904	0.48535	0.0001

ADDITIONAL DIAGNOSTICS:
F = 7,042.7 ADJUSTED R-SQUARED = .9337
NUMBER OF OBSERVATIONS = 3,000
CONDITION INDEX = 23.89

Table 4.17. Statistics for Annual Variable Cost Equation For Fixed Big Gun System

	Parameter Estimate	Standard Error	Probability > |T|
INTERCEPT	-88.61	2.87375	0.0001
VD	0.1970	0.00409	0.0001
NOD	1.9271	0.01127	0.0001
CE	62.744	1.61790	0.0001
CROPPC	0.8144	0.28148	0.0038
WAGERT	6.1070	0.35280	0.0001
SD	33.576	0.43460	0.0001

ADDITIONAL DIAGNOSTICS:
F = 8,005.5 ADJUSTED R-SQUARED = .9412
NUMBER OF OBSERVATIONS = 3,000
CONDITION INDEX = 23.89

Table 4.18. Statistics for Annual Variable Cost Equation For Traveling Gun System

	Parameter Estimate	Standard Error	Probability > |T|
INTERCEPT	-64.373	3.2489	0.0001
VD	0.16920	0.0047	0.0001
NOD	1.82810	0.0131	0.0001
CE	75.2723	1.8225	0.0001
CROPPC	4.24642	0.3309	0.0001
WAGERT	1.43639	0.4096	0.0005
SD	22.7987	0.5058	0.0001

ADDITIONAL DIAGNOSTICS:
F STATISTIC = 4,939.4 ADJUSTED R-SQUARED = .9081
NUMBER OF OBSERVATIONS = 3,000
CONDITION INDEX = 23.23

Table 4.19. Statistics for Annual Variable Cost Equation For Center Pivot System

	Parameter Estimate	Standard Error	Parameter Probability > |T|
INTERCEPT	-61.849	3.11268	0.0001
VD	0.16906	0.00444	0.0001
NOD	1.75126	0.01227	0.0001
CE	78.8700	1.74711	0.0001
CROPPC	1.83790	0.30646	0.0001
WAGERT	1.22149	0.38382	0.0015
SD	18.2855	0.47237	0.0001

ADDITIONAL DIAGNOSTICS:
F STATISTIC = 4,971.46 ADJUSTED R-SQUARED = .9086
NUMBER OF OBSERVATIONS = 3,000
CONDITION INDEX = 23.81

Continuing with the center pivot example and using the data in Table 4.9, the equation will be explained as follows. If the conditions in Table 4.20 are true, the estimated annual variable cost on a per acre basis would be $136.10, or multiplying by 100 acres, the estimated annual variable cost would be $13,610 for this system. The interpretation of the parameters is straight forward as in this linear function the parameter estimates are multiplied by the site data, and all variables are summed to estimate the annual variable cost for the system. As illustrated in Table 4.2, the cost estimate is based on the center pivot system operating 45 days on a medium water holding capacity soil.

Table 4.20. Example of Using the Center Pivot Variable Cost Equation

Site Variable	Parameter Data	Estimate	Value
INTERCEPT	1	- 61.85	-$61.85
VD	50	0.16906	$8.45
NOD	45	1.7513	$78.81
CE	1.05	78.87	$82.81
CROPPC	2.5	1.838	$4.59
WAGERT	4.5	1.221	$5.50
SD	1	17.787	$17.79
			===
		Per Acre Variable Cost	$136.10

The impact on annual variable cost associated with a change in a variable can be estimated by taking the first derivative of the variable cost equation with respect to the variable in question. For example, the first derivative of the NOD variable is a constant of 1.7513. Therefore, if the season is abnormally dry and the center pivot system had to run 60 days instead of the assumed 45 days, the extra 15 days of operation would cost an extra $26.27 per acre.

The variable SD is a dummy variable where the parameter estimate is an estimate of the variable irrigation cost associated with the soil type or water holding capacity of the soil. Table 3.2 lists the difference in production costs associated with the different water holding capacity soils. The high water holding capacity soil has the lowest cost, medium capacity has the median cost, and low water holding capacity soil has the highest cost. With this relationship in mind between water holding capacity and cost, Table 4.14 lists the value for SD as it relates to the soil type.

Table 4.21. Dummy Variable Value Associated with Soil Type

Value for SD	Soil Type
0	High Water Holding Capacity
1	Medium Water Holding Capacity
2	Low Water Holding Capacity

When SD is zero, the input cost without considering the additional irrigation cost, or the non-irrigation cost, is lowest and when SD is two, the non-irrigation cost is the highest, ceterus paribus. The parameter estimates for the variable SD show that the cost is increasing as the value of SD increases. Since the variable SD increases as its water holding capacity decreases, the variable cost of irrigation increases as the water holding capacity of the soil decreases.

To interpret these findings, the value of the parameter estimate for SD in the center pivot equation is 17.79. This means the per acre variable cost will increase $17.79 as the soil type changes from high water holding capacity to medium water holding capacity, and as the soil type changes from medium water holding capacity to low water holding capacity. The per acre increase in variable costs from irrigating a low water holding capacity soil instead of an high water holding capacity soil is $35.58.

4.8 Total Annual Cost of Irrigation

Since the fixed cost component and the variable component have been separated, they must be combined in order to evaluate total cost. Continuing with the center pivot example, the expected total cost of irrigation, under the above assumptions, would be $237.79 per acre.

Prior to buying a center pivot system, this total cost estimate must be compared to the expected benefits of irrigation. The benefits of irrigation must be at least equal to this $237.79, assuming risk preferences to be neutral, or a rational person would not buy

the system. Assuming the selling price of corn to be $2.50 per bushel, a producer would have to increase production an average of 95.1 bushels per acre to breakeven in the above example.

Assuming the decision to purchase this center pivot system is made, the fixed cost of $101.69 is an expense that must be paid every year. Now the evaluation of whether to use the irrigation system or not to use the irrigation system is based on the criteria that the increased revenues will exceed, or at least equal, the variable cost of irrigation. The criteria changes from the total cost to only the variable cost, because the system has been purchased and the fixed cost must be paid whether the system is operating or not. Therefore, in the short run the variable cost of operating the system is the only cost that must be covered by the expected benefits. If dollar returns exceed variable costs, the extra money would be used to pay the annual fixed costs.

Since the weather in any one year is random, the 45 days that are used in the example calculation need to be allocated over the season to yield the highest returns. Since the pollination period has been shown to be the most beneficial period to irrigate, a number of days should be allocated for this time (Daniels). However, outside this period, the $1.75 per acre cost of irrigating every day gives a farmer some information to determine if irrigation on any particular day is a good decision or not.

CHAPTER 5

Interpreting Results of Econometric Models

5.1 Comparison of Models

The irrigation cost models for the four different systems have been explained in the preceding chapter. This chapter will interpret the results and explain how to use these models. First, the four irrigation systems will be compared based on irrigation cost relative to field size. Second, using assumptions about increased yield associated with irrigation; and the best and worst case corn prices, the center pivot models will be used to estimate whether a certain set of agronomic, meteorological, and economic parameters yield a profitable environment for irrigation.

Cost comparisons are used to compare the cost structure of the four systems. An arbitrary low and high value is selected for each value where the low valus is less than the mean of the range and the high value is higher than the mean of the range. Table 5.1 lists the values used for each of the variables in the two scenarios that will be used to show how the econometric models could be used.

The cost equations are linear, except for the variable, acre. As the graph in Figure 5.1 shows, total cost falls as acres increase. This logically fits a field situation as overhead cost, such as engines, pumps, pipe from water source to field, and other irrigation equipment, increases marginally when the system is expanded for larger fields.

Table 5.1. Variable Values for Cost Analysis

VARIABLE	LOW	HIGH
HD	3,000	14,000
VD	75	225
IR	7.5%	18.0%
CE	$1.00	$1.30
CHP	$ 125	$ 175
CROPPC	$1.75	$3.00
WAGERT	$3.80	$5.50
NOD	40	120
SD	1	1

Therefore, per acre cost declines quickly as acreage is initially increased, but fixed cost increases marginally when field size is relatively large, causing the curves to flatten.

In Figure 5.1, the portable pipe system produces the lowest cost up to its field size capacity of 80 acres. Since the cost of managing two systems is assumed to be prohibitive, the traveling gun system has cost advantages from 80 acres to 110 acres, the assigned maximum limit for traveling gun system. Finally, from 110 acres to 300 acres, the center pivot produces the lowest cost.

In the high cost scenario shown in Figure 5.2, the center pivot system is the lowest cost system from its minimum field size of 30 acres to 300 acres. The traveling gun system is the lowest cost irrigation system for fields less than 30 acres to its minimum field size of 10 acres. Below 10 acres, the portable pipe system produces the lowest

cost. Table 5.2 summarizes the lowest cost irrigation system from the information in Figure 5.1 and Figure 5.2.

As Table 5.2 shows, different field situations yield different cost structures among these irrigation systems. These models can be used to determine which system minimizes irrigation cost. This analysis shows that different situations will result in different least cost irrigation systems.

Table 5.2. Least Cost Irrigation Systems from Min/Max Analysis

	Low Scenario	High Scenario
Portable Pipe	less than 20 acres	less than 10 acres
Big Fixed Gun	20 to 80	None
Traveling Gun	80 to 110 acres	10 to 30 acres
Center Pivot	more than 110 acres	more than 40 acres

5.2 Expected Benefits of Irrigation

The focus of this thesis is on estimating irrigation cost. However, to determine the economic feasibility of irrigation, the expected increase in revenues generated by adding the additional water to a field of corn through irrigation must be addressed. Two variables, price of corn and expected increase in corn yield caused by the additional water being applied to the crop, can be multiplied together to calculate the expected benefits irrigation adds to the operation. By assuming values for these two variables,

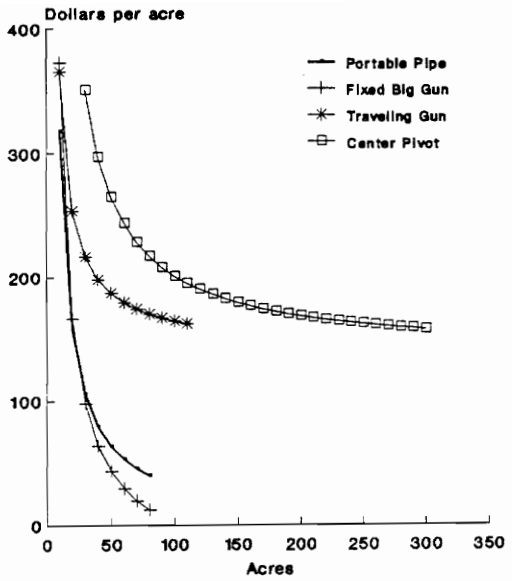

Figure 5.1. Comparing Total Cost Across Irrigation Systems For Low Cost Scenario

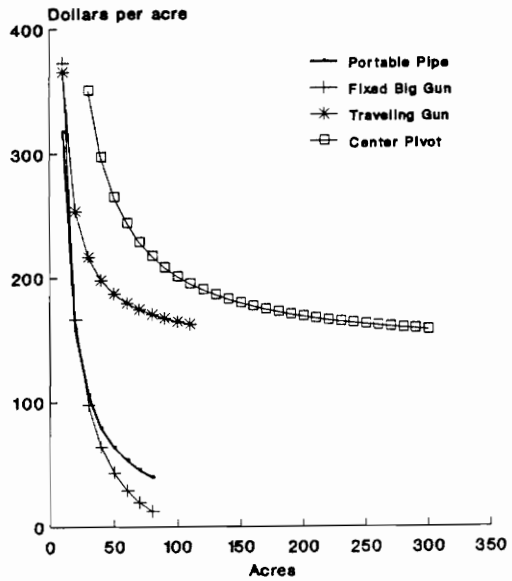

Figure 5.2. Comparing Cost Across Irrigation Systems For High Scenario

these cost models can be utilized to assess the profitability of an irrigation investment. If irrigation cost exceeds the expected increase in benefits, an irrigation system should not be built.

Analyzing the impact that increased corn yield could have on corn prices in Virginia is beyond the scope of this study. Therefore, this analysis assumes that the overall increase in corn production associated with irrigation would have no impact on the price of corn. This assumption is used often in economic analysis of a free enterprise system as the action of one person is too small to significantly impact the supply and demand situation.

A historical analysis of corn prices in Virginia are a guide for determining where prices will be in the future. Corn prices from 1978 through 1982 are obtained from the Virginia Crop Reporting Service and are shown in Table 5.3. Since USDA had a large impact on prices in 1983 with their payment in kind (PIK) program, 1983 prices are excluded from the averages as PIK was an unsual event that is not expected to recur. Also, irrigation costs are based on 1983 prices and to compare revenues to cost, prices must be in constant dollars so the analysis is not biased by inflation.

The mean corn price from 1978 through 1982 is $2.78 per bushel. Prices ranged from a low of $2.35 per bushel to a high of $3.48 per bushel. The mean price of $2.78 is the most likely estimate of future prices in 1983 dollars and will be used to estimate the expected benefits derived from irrigation.

Table 5.3. Annual Corn Prices Used to Obtain Five Year Average[1]

YEAR	Corn Price ($ per bushel)
1978	$2.35
1979	$2.83
1980	$3.48
1981	$2.70
1982	$2.55
Average Price for Period	$2.78

[1] Taylor, et al.

The other factor in the expected benefit function is the expected increase in corn yields derived from irrigation. Yield estimates are highly variable from site to site as yields fluctuate with different levels of management practices (fertilization levels, weed control practices, insect control practices, irrigation policy) and different environmental factors (soil type, soil texture, amount of rainfall, timing of rainfall, air temperature). Yields without irrigation are highly erratic and play a big part in the expected benefits gained from irrigation. Some years when the rain is sparse, non-irrigated yields will be quite low and the difference between non-irrigated yields and irrigated yields will be quite large. The timing and impact of dry weather on the profitability of irrigation may be large, but the following analysis assumes average yields.

Assuming values for the variables impacting the dollar benefits and comparing them to the cost associated with irrigation demonstrate how these models can be used. To demonstrate the use of these four models, the Pamunkey River plain will be used as this area has productive soils that respond well to irrigation (Taylor, et al.). Using the center pivot model, the cost and benefits of irrigation will be evaluated to demonstrate how these models can be utilized to make decisions concerning the economic viability of irrigation projects.

To obtain the yield benefit of irrigation, the nonirrigated and irrigated yield of land in the Pamunkey River basin is estimated. For nonirrigated acreage, water is assumed to be the limiting factor in the long run, all other inputs will be managed to obtain the highest yields possible, and rainfall is assumed to follow historical patterns. Since water availability and storage differs on the three different soil types, each soil type is assumed to have different yield potentials when irrigation is not used.

Next, all inputs are assumed to be managed to achieve maximum yields on the center pivot system. The yields shown in Table 5.4 are based on Dr. Blake Ross' years of experience working with irrigators in this region and the nonirrigated yields represent expected yields for each soil type in an average year. Using the difference between the irrigated and nonirrigated yields and multiplying this difference by the expected farm price, expected benefits are calculated and shown in Table 5.4.

Table 5.4. Expected Benefits from Irrigating Corn

Soil Texture	Irrigated Yield	Nonirrigated Yield	Increased Revenues
Coarse	190	80	$305.80
Fine	190	100	$250.20
Medium	190	120	$194.60

5.3 Comparing Expected Benefits to Expected Cost

Making a rational decision about purchasing an irrigation system is complex. On the benefit side, the selling price of corn plays a critical role and prices are variable from year to year. Future prices are unknown, forcing the decision to be based on an individual's assessment of the probability of future events and the impact these events may have on the profitability of irrigation.

Futhermore, profitability is only one reason why a producer would invest in an irrigation system. Another reason that is critical is the producers ability to reduce his risk with this investment. Droughty weather can cause non-irrigated yields to plunge while a producer using an irrigation system can expect yields which are more stable. With more stable yields, revenues will be more stable and the producer has reduced his risk. This may play a large role in the irrigation investment decision to the point where the benefit to cost ratio may be less than one, but the producer still makes the investment

because his risk has been reduced. Risk reduction of irrigation systems and its perceived value to producers should be investigated.

On the cost side, weather patterns play a critical role. Once again, future weather patterns, or more specifically droughts, can not be predicted leading to a decision based on probabilities. Understanding these probabilities will help a producer make decisions, but the first step is to determine the the most likely scenario. Figures 5.3 through 5.5 use one scenario to portray the expected cost and benefits of each irrigation system over three different soil types.

The information in Table 5.5 is the data used to generate annual irrigation cost through the irrigation cost equations. The data points are generated by calculating cost while the number of irrigation days increases from 44 days to 122 days for each soil class. By calculating the increased revenues expected from irrigating each soil class and the increased cost associated with the number of days the system will be operating, the number of operating days each system can utilize before costs exceed benefits can be determined.

Figures 5.3 through 5.5 show the breakeven days associated with each water holding capacity soil. The vertical line is drawn where cost and revenues intersect. To the left of the vertical line, revenues exceed costs. To the right of this line, costs exceed revenues.

Table 5.5. Field Parameters for Benefit-Cost Example

ACRES.....	200
HORIZONTAL DISTANCE (FT)	5,500
INTEREST RATE.....	11.50%
VERTICAL DISTANCE (FT)..	75
PUMP COST ($/HP).....	$150
FUEL COST ($/GAL).....	$0.95
CROP PRICE ($/BU).....	$2.78
WAGE RATE ($/HR).....	$3.50

5.4 Probability of Revenues Exceeding Cost

Under the analysis shown in Section 5.4, the number of days the irrigation system can be operated, before cost will exceed the revenues generated by irrigation, is calculated. At the point cost and benefits are equal, the breakeven point, an estimate for the number of days the system can operate before costs exceed revenues is obtained.

This breakeven point can be compared to the number of irrigation days expected 50 percent of the time based on the historic drought day information. If the number of drought days expected 50 percent of the time will be less than the number of days the system can operate before costs exceed revenues, erecting an irrigation system on this particular site would be a rational decision, but would not guarantee success. Table 5.6 summarizes the breakeven points and compares these days with the number of drought days expected 50 percent of the time over the growing season in the Pamunkey river area. (Vellidis, Ross, and Taylor).

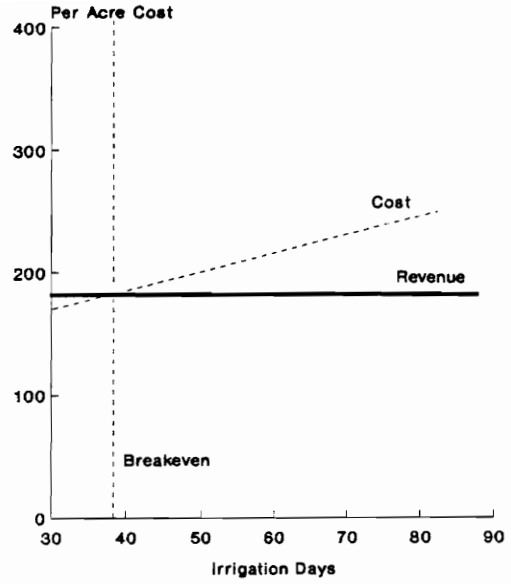

Figure 5.3. Benefit-Cost Analysis for Six-Inch BASIS Soil

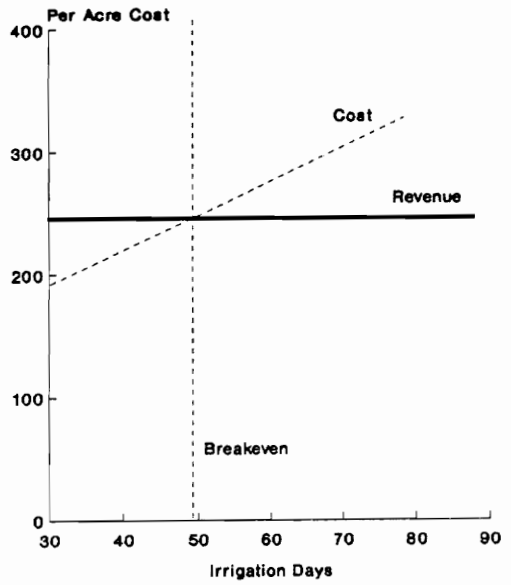

Figure 5.4. Benefit-Cost Analysis for Four-Inch BASIS Soil

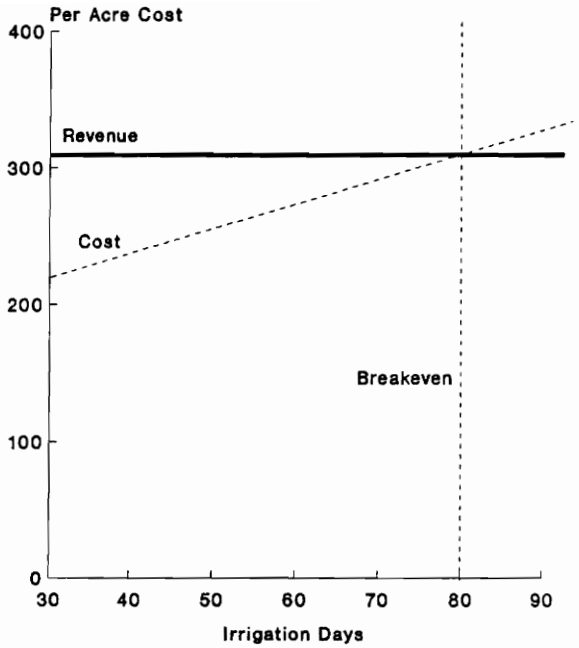

Figure 5.5. Benefit-Cost Analysis for Two-Inch BASIS Soil

Table 5.6 shows that all soil classes under the field parameters described in Table 5.4 are expected to operate at a point where revenues will exceed cost. Therefore, if a site met the criteria in this scenario, this site would certainly merit further analysis as the expected value analysis indicates that the irrigation investment would have positive returns.

Table 5.6. Comparing Breakeven Point with Expected Drought Days

Waterholding Capacity of the Soil	Breakeven Point Number of Days	Expected Drought Days 50% of the Time
High	38	13
Medium	59	25
Low	80	53

CHAPTER 6

Summary, Conclusions and Implications for Future Research

6.1 Summary of Study

This study's objective is to create a tool for Virginia water policy planners that would help them make better future policy decisions. Riparian doctrine guides the consumption of public water in Virginia and ownership rights concerning the allocation of a scarce river water supply are not defined by this doctrine. As large scale irrigation systems are being installed in Virginia, and urban water needs expanding, the demands on the river water systems could surpass the supply. Therefore, ownership rights or public policy will have to be defined so public water can be allocated appropriately. This study provides objective information which will help public policy planners to project future irrigation water use and design sound policies.

Public policy planners need to understand the incentives that motivate decisions and how these incentives impact individual decisions. Microeconomic theory of production economics uses profit maximization as the objective of an individual producer. Profit maximization has a revenue component and a cost component and this study provides information on the cost perspective. Two conditions lead the study to focus on cost models.

First, production functions for corn under field conditions are not very precise and forecasting future corn prices is even less precise. Spending resources to create more

accuracy in estimating corn's response to irrigation and estimating future corn prices was beyond the scope of this study. Therefore, expert opinions are used to project the revenue from irrigation.

Second, a good estimate of the cost of irrigation can be used in conjunction with the revenue assumptions to project likely outcomes associated with the irrigation purchase decision. Spending resources on creating irrigation cost estimates is considered to be the best use of the resources.

The first step in this cost estimation process is to build an intelligent design model which incorporated the experience and knowledge of experts in the irrigation design field. Using this experience, design models are created for the portable pipe, fixed big gun, traveling gun, and center pivot irrigation systems. These systems used agronomic, meteorological, and engineering principals to design the layout of the system, calculate the amount of water that must be delivered to the field, the energy cost to deliver this water, and the cost of all the irrigation components needed to build the system.

These design models are used in a simulation analysis. This simulation analysis uses random numbers within predefined ranges to create a database containing cost information related to the particular situation being simulated with the associated field and irrigation system parameters. For each irrigation system, the model is simulated 3,000 times.

The second step in this cost estimation process is to summarize this information into an econometric model. This process starts by determining the functional form of the

relationship between the variables and their cost. This analysis indicated all variables were linearly related, except for the variable related to field size (ACRES). Upon further analysis, field size was linearly transformed by using its inverse.

Since all variables had a linear relationship with cost, ordinary least squares are employed to determine which variables are statistically significant. Since type II errors are likely with this large sample, and the design models are relatively similar across all irrigation systems, another criteria is also employed to determine significant relationships. Since each design model utilizes consistent logic, variables were eliminated from the econometric model if they are not statistically significant in all econometric models. Multicollinearity is a problem with the variable cost equation and correcting this problem eliminated consumptive use of water as a variable.

After all variables have been selected, parameter estimates for each variable are calculated. Three stage least squares and ordinary least squares are both utilized in the parameter estimation process. Parameter estimates from both procedures are compared and the ordinary least square estimates are determined to be adequate as the more sophisticated three stage process is determined to add no additional information to the estimation process.

Once the models have been estimated, they are explained and used in various scenarios. An analysis comparing the various systems under different field situations shows that different field situations created different least cost irrigation systems. Another analysis calculates the breakeven number of days the irrigation system could

be operated before costs exceed revenues. Finally, the breakeven number of days is compared to the number of drought days expected in Virginia's Pamunkey river basin 50 percent of the time, and investing in the irrigation system is determined to yield positive returns.

6.2 Conclusions of Study

After reviewing the output from the econometric irrigation design models, they are determined to be reasonably accurate in estimating the expected cost of irrigation. Using at most 10 irrigation related parameters, costs for a portable pipe, fixed big gun, traveling gun, and center pivot systems are estimated for irrigating corn in Virginia for any field location. This econometric approach is a time saving tool that can quickly eliminate those situations which can not economically support an irrigation system using corn price and irrigation yield assumptions in conjunction with the cost projections.

Once this econometric analysis has been completed and a group of irrigation sites have been identified as being economically viable, the design models could be used to estimate a more precise cost for these locations. These models are not presently user friendly, but anyone knowing the computer language called BASIC could enter the information for a particular site to get a more precise cost estimate. Once again, this analysis would quickly yield those field locations which have a high probability to economically support an irrigation system using corn price and irrigation yield assumptions in conjunction with the design model's cost projections.

If more precise cost estimates are needed to select the economically feasible field locations in Virginia, agricultural engineers specializing in irrigation system design would have to travel to each field location, design an irrigation system for the location, and then very precise cost estimates could be made. If this level of analysis is needed, the tools devised in this study will greatly reduce the time and cost of such analysis through the elimination of those locations which are not likely to be economically feasible.

From a producer's perspective, these tools are superb planning methods that will allow a producer to analyze a particular irrigation investment decision in a cost effective manner. The model will quickly estimate the cost to irrigate a particular field site. With some drought information, corn price assumptions, and irrigated corn yield assumptions, the economic implications of investing in the irrigation system for this particular site can be analyzed. The long term implications of this investment can be properly addressed by the producer using these tools.

6.3 Implications for Future Research

The design models are not user friendly. Making the design models user friendly is an extension of this study that would be beneficial to Virginia's producers and water resource planners. Extending these design models by incorporating the drought day information into the models would increase their usefulness by making them more interactive. These interactive models could be designed, so the producer could input

their assumed increase in corn yields, their assumed future corn prices, and their desired return on investment; and the model would estimate the probability that the irrigation investment has returns that meet the producer's expectations.

Another extension of this research is to expand the number of crops analyzed. Whether the crop is soybeans, sunflowers, wheat, barley, oats, rye, or some other crop, the methods used to build these irrigation models for corn would be very similar for these crops. Once these parameters have been changed to reflect the crop water needs, irrigating a site under different crop rotations could be analyzed.

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APPENDIX A

This appendix contains the three design programs written in the BASIC computer language. Each of the written programs can be found on the following pages.

Program	Page
Center Pivot System	117
Traveling Gun System	122
Portable Pipe and Fixed Big Gun System	128

```
1 REM*******************************************************************************
2 REM              HIGH PRESSURED CENTER PIVOT SYSTEMS
3 REM                   by: ALAN B. LANIER
4 REM*******************************************************************************
10 REM******************************************************************************
20 REM
40 REM                 SECTION I: ASSIGNED VALUES
45 REM
50 REM******************************************************************************
60 CLS
70 DIM IPH(3),AMC(3),CFL(2),CFM(2),CFS(2),PE(3)
80 DEFSNG N
90 FOR K=1 TO 3
100 REM*****************************************************************************
110 REM IPH = INCHES PER HOUR; AMC = AVAILABLE MOISTURE CONTENT
120 REM "PE" = PUMPING EFFIENCY OF PUMP; "BI" = ADDITIONAL CROP INPUTS
130 REM "ST$" = SOIL TYPE WHERE "1"= MEDIUM "2"= FINE "3"= COARSE
140 REM*****************************************************************************
150 READ IPH(K),AMC(K), PE(K),YPA(K),BI(K),ST$(K)
160 DATA .4,.2,.65,120,59.14,MEDIUM,.3,.133333,.8,100,76.57,FINE,.5,.06667,.9,80
,97.42,COARSE: REM VALUES OF PARAMETERS THAT CHANGE BY SOIL TYPE
170 NEXT K
180 REM "CF"= FRICTION COEFFICIENT; "TOP1"= PCV PIPE; "TOP2"= ALUMINUM PIPE
190 CF(1)=120:CF(2)=150:TOP1=2:TOP2=1
200 SD=31:RD=30:REM "SD"= PLANT ROOTS CAN NOT PENETRATE PAST THIS DEPTH;********
**********************"RD"= MAXIMUM DEPTH CORN ROOTS CAN GROW
201 PIE = 22/7
240 REM*****************************************************************************
250 REM
270 REM       SECTION II: RANDOM SELECTS VALUES FOR THE MODEL'S PARAMETERS
275 REM
280 REM*****************************************************************************
285 REM COUNT =998
290 FOR I = 1 TO 3 STEP 1: REM DETERMINES SOIL TYPE PROGRAM WILL ANALYSE
300 IF I = 1 THEN GOTO 330: REM DEFINES "HIGH" WATER HOLDING SOIL
310 IF I = 2 THEN GOTO 340: REM DEFINES "MEDIUM" WATER HOLDING SOIL
320 IF I = 3 THEN GOTO 350: REM DEFINES "LOW" WATER HOLDING SOIL
330 NOD = INT(RND(23)*(88+1)):IF NOD < 1 THEN GOTO 330 ELSE GOTO 360: REM FOR A
*********"HIGH" WATER HOLDING SOIL, THE NUMBER OF DAYS THE SYSTEM MUST OPERATE TO
*********KEEP THE SOIL MOISTURE AT 50% CAPACITY IS MORE THAN 1 DAY
340 NOD = INT(RND(31)*(103+1)):IF NOD< 1 THEN GOTO 340 ELSE GOTO 360: REM FOR A*
********"MEDIUM" WATER HOLDING SOIL, THE NUMBER OF DAYS THE SYSTEM MUST OPERATE *
********TO KEEP THE SOIL MOISTURE AT 50% CAPACITY IS MORE THAN 1 DAY
350 NOD = INT(RND(83)*(123+1)):IF NOD < 1 THEN GOTO 350: REM FOR A "LOW" WATER
HOLDING SOIL, THE NUMBER OF DAYS THE SYSTEM MUST OPERATE TO KEEP THE SOIL
MOISTURE AT 50% CAPACITY IS MORE THAN 1 DAY
360 ACRE = INT(RND(1)*(300+1)):IF ACRE < 30 THEN GOTO 360:REM RANDOM SELECTION
****** OF THE NUMBER OF ACRES TO BE IRRIGATED WHERE 0 < ACRES <= 80
380 HD = INT(RND(5)*(15840+1)):IF HD<50 THEN GOTO 380:REM RANDOM SELECTION OF
****** THE DISTANCE FROM THE WATER SOURCE TO THE EDGE OF FIELD
390 VD = INT(RND(1)*(300+1)):IF VD<5 THEN GOTO 390:REM RANDOM SELECTION OF THE
****** DISTANCE FROM THE TOP OF THE WATER TO THE HIGHEST RISER/EMITTER
400 CE = RND(12) * 1.5: IF CE < .75 THEN GOTO 400: REM "CE"= COST OF FUEL
410 COIL = CE * 4: REM "COIL"= COST OF OIL FOR LUBRICATING THE PUMP
420 CHP = RND(25) * 225: IF CHP < 125 THEN GOTO 420:REM "CHP"= PUMP COST********
************************************************** PER HORSEPOWER
430 IR = RND(13) * .25: IF IR < .05 THEN GOTO 430: REM "IR"= INTEREST RATE
440 CU = RND(17) * .25: IF CU<.2 THEN GOTO 440: REM "CU"= PLANT'S DAILY WATER***
**********************************************************CONSUMPTION
```

```
445 TP = .5:REM RND(3)*.7: IF TP<.4 THEN GOTO 445: REM "TP"= TRIGGER POINT
450 CROPPC = RND(41)*(5.564): IF CROPPC < 1.391 THEN GOTO 450:REM "CROPPC"=
******** SELLING PRICE OF CORN
460 WAGERT = RND(54)* 6.7: IF WAGERT < 3.35 THEN GOTO 460:REM "WAGERT"= WAGE****
**********************************************************************************RATE
470 REM*********************************************************************************
471 REM
480 REM SECTION III: SYSTEM DESIGN, OPERATING TIME AND WATER FLOW REQUIREMENTS
481 REM
490 REM*********************************************************************************
500 R = ((ACRE*43560!)/(PIE))^.5:REM LENGTH OF ARM
510 AACRE = (R^2*PIE)/43560!:REM ACTUAL ACRES IRRIGATED
520 DPI = (AMC(I)*TP*RD)/CU:REM DAYS PER IRRIGATION
525 TPI = DPI*24:REM HOURS PER IRRIGATION CYCLE
530 WAI = (DPI*CU)/.8: REM WATER APPLIED PER IRRIGATION
540 GPM = (AACRE*WAI*453)/TPI: REM GALONS PER MINUTE
560 REM*********************************************************************************
561 REM
570 REM    SECTION IV: SIZING PIPE, COSTING PIPE AND DETERMINING HORSEPOWER
571 REM
580 REM*********************************************************************************
585 REM ROUTINE TO SIZE MAIN PIPE UNTIL SO VELOCITY IS LESS THAN 5 FT/SEC
586 REM*********************************************************************************
590 SD1 = 4
600 SD1 = SD1+2
610 V3=(.408*GPM)/(SD1^2): REM VELOCITY OF WATER IN MAIN PIPE
620 IF V3 > 6 THEN GOTO 600:REM SIZING PIPE TO A VELOCITY CONSTRAINT
624 REM*********************************************************************************
625 REM BASED ON PIPE SIZE, THE PER FOOT COST OF THE PVC PIPE & BURYING
626 REM*********************************************************************************
630 IF SD1=4 THEN CM = 2.5: REM THE FOLLOWING ASSIGNS THE COST PER FOOT OF THE M
AINLINE PIPE AND THE COST OF BURYING
640 IF SD1=6 THEN CM = 3
650 IF SD1=8 THEN CM = 4.25
660 IF SD1=10 THEN CM = 6.25
670 IF SD1=12 THEN CM = 8.5
674 REM*********************************************************************************
675 REM DETERMINE DIAMETER OF CENTER PIVOT ARM BASED ON WATER FLOW
676 REM*********************************************************************************
680 IF GPM <  930 THEN D=6  :GOTO 720
690 IF GPM < 1080 THEN D=6.5:GOTO 720
700 IF GPM > 1080 THEN D=7.5
720 V1=(.408*GPM)/(D^2): REM VELOCITY OF WATER IN MAIN PIPE
724 REM*********************************************************************************
725 REM HORSEPOWER REQUIREMENTS BASED ON FRICTION LOSS & REQUIRED PRESSURE
726 REM*********************************************************************************
730 HFL = (((2.3*V1)/((1.318*(CF(TOP2))*((D/12)^.63)))^1.852)*.33):REM FRICTION
LOSS IN CENTER PIVOT ARM ON A PER FOOT BASIS
740 HFM = (((2.3*V3)/((1.318*(CF(TOP1)))*((SD1/12)^.63)))^1.852):REM FRICTION LO
SS IN MAIN (PER FOOT)
760 PSI=2.31*70
770 TH = VD + (HFL*R) + (HFM*(HD+R)) + PSI:REM TOTAL HEAD
780 HP% = (TH*GPM)/(3960*PE(2)) + .5: REM HORSEPOWER OF PUMP
781 HPG% = (.02*R)+.5: REM HORSEPOWER REQUIREMENTS OF GENERATOR MOTOR
785 REM*********************************************************************************
786 REM
790 REM      SECTION V: COMPUTING VARIABLE COST FOR THE IRRIGATION YEAR
791 REM
792 REM*********************************************************************************
800 HPHR = ((NOD/DPI)*(HP%+HPG%)*TPI)+.5:REM BRAKE-HORSEPOWER-HOURS PER YEAR
```

```
805 LABHR = ((NOD/DPI)*1!)+(NOD*.5):REM TIME SPENT STARTING THE SYSTEM          *
***(1/2 HR. PER START) AND OBSERVING EACH DAY OF OPERATION (2 TIMES @ 15 MIN.)
807 LABTRAN = (2*NOD*.5):REM TIME SPENT TO GET TO FIELD 2 TIMES PER DAY @ 30 MIN
808 LABHRS = LABHR+LABTRAN:REM TOTAL HOURS OF LABOR PER SEASON
810 LABCOS = LABHRS*WAGERT:REM COST OF LABOR
820 GALD = HPHR/14.6:REM GALLONS OF DIESEL FUEL CONSUMED PER YEAR
830 GALO = HPHR/3000:REM GALLONS OF OIL CONSUMED PER YEAR
840 MAINT = HPHR*.002:REM MAINTENANCE COST PER YEAR
845 COLP = .02*YPA(I)*CROPPC*AACRE: REM LOST PRODUCTION COST DUE TO IRRIGATION
850 VC =(GALD*CE)+(GALO*COIL)+MAINT+(BI(I)*AACRE)+COLP+LABCOS:REM ANNUAL
********* VARIABLE COST
855 VCPA = VC/AACRE: REM SEASON'S VARIABLE COST PER ACRE FOR THE YEAR
856 REM*************************************************************************
857 REM
860 REM           SECTION VI: COMPUTING FIXED COST OF SYSTEM
861 REM
865 REM*************************************************************************
866 REM DETERMINING THE COST OF THE CENETER PIVOT ARM BASED ON ITS LENGTH
867 REM*************************************************************************
870 IF R<1445 THEN CCPPF = R*28:GOTO 910:REM COST OF LATERAL ARM
880 IF R<1560 THEN CCPPF = R*32:GOTO 910
890 IF R<1900 THEN CCPPF = R*34:GOTO 910
900 IF R<2040 THEN CCPPF = R*37:GOTO 910
905 REM*************************************************************************
910 GENPAD = (7*R)+500: REM COST OF GENERATOR AND CEMENT FOR PIVOT CENTER
920 PUMPC = CHP*HP%: REM PUMP COST BASED ON HORSEPOWER OF PUMP
925 CMP = (HD+R)*CM: REM TOTAL COST OF BUYING AND BURYING MAIN PIPE
930 INVES = CCPPF+PUMPC+CMP+GENPAD: REM INVESTMENT COST OF PIVOT SYSTEM
935 INVESPA = INVES/AACRE: REM INVESTMENT COST PER ACRE
936 REM**********ANNUALIZING THE INVESTMENT COST OF PIVOT SYSTEM****************
937 REM*************************************************************************
940 CRF = IR/(1-(1+IR)^(0-15)):REM CAPITAL RECOVERY FUND
950 AIC = INVES*CRF:REM ANNUAL INVESTMENT COST
955 REM*************************************************************************
970 IRS = INVES*.02: REM ANNUAL COST OF INSURANCE AND TAXES
980 AFC = AIC+IRS:AFCPA = AFC/AACRE:REM ANNUAL FIXED COST OF SYSTEM
983 AFCPA = AFC/AACRE: REM ANNUAL FIXED COST ON A PER ACRE BASIS
984 REM*************************************************************************
985 REM
986 REM**SECTION VII: COMPUTING THE ANNUAL COST OF OPERATING A PIVOT SYSTEM
987 REM
988 REM*************************************************************************
990 ATC = AFC+VC: REM ANNUAL TOTAL COST OF OPERATION
991 ATCPA = ATC/AACRE: REM ANNUAL TOTAL COST PER ACRE
992 BEY=ATCPA/CROPPC:REM BREAKEVEN YIELD FOR IRRIGATION
993 REM*************************************************************************
994 GOTO 10000
1000 LPRINT"*************************************************************************"
1005 LPRINT"********DETAILED DIAGNOSTIC PRINTOUT FOR CENTER PIVOT SYSTEM*******"
1010 LPRINT"*************************************************************************"
1015 LPRINT""
1019 LPRINT "TYPE OF SOIL = ........................................";ST$(I)
1020 LPRINT USING"TOTAL ACRES IRRIGATED = ............................. ###.#"
;AACRE
1022 LPRINT USING"DIAMETER OF THE FIELD (in feet) = ................... #,###.#"
;AACRE
1025 LPRINT USING "WATER HOLDING CAPACITY (in. of water per in. of soil) = #.###
";AMC(I)
1026 LPRINT USING "NUMBER OF DAYS SYSTEM WILL OPERATE DURING THE YEAR = .... ###
";NOD
```

```
1027 LPRINT USING "NUMBER OF DAYS TO IRRIGATE THE FIELD = ..... #.###
";DPI
1030 LPRINT USING "VERTICAL DISTANCE IN FEET = ..... ###.#
";VD
1035 LPRINT USING "HORIZONTAL DISTANCE = ..... ####.#
";HD
1036 LPRINT USING "PERCENT OF AVAILABLE WATER TO TRIGGER IRRIGATION = .. ##.###%
";TP*100
1040 LPRINT USING "WATER APPLIED PER IRRIGATION IN INCHES = ..... #.###
";WAI
1045 LPRINT USING "PLANT'S DAILY WATER REQUIREMENTS IN INCHES = ..... #.###
";CU
1047 LPRINT ""
1050 LPRINT USING "COST OF FUEL IN DOLLARS PER GALLON =..... $#.###
";CE
1055 LPRINT USING "COST OF OIL IN DOLLARS PER GALLON = ..... $#.###
";COIL
1060 LPRINT USING "HORSEPOWER COST ON A COST PER HORSEPOWER BASIS =..... $###.#
";CHP
1065 LPRINT USING "SELLING PRICE PER BUSHEL OF CORN = ..... $#.###
";CROPPC
1066 LPRINT USING "YIELD WITHOUT IRRIGATION = ..... ###
";YPA(I)
1070 LPRINT USING "HOURLY WAGE RATE FOR LABOR = ..... $#.###
";WAGERT
1075 LPRINT USING "COST OF CAPITAL (INTEREST RATE) = ..... ##.##%
";IR*100
1080 LPRINT"*****************************************************************"
1084 LPRINT USING "TOTAL ANNUAL COST OF CENTER PIVOT =..... $##,###.#
#";ATC
1085 LPRINT USING "TOTAL ANNUAL PER ACRE COST OF CENTER PIVOT =..... $###.#
#";ATCPA
1090 LPRINT"*****************************************************************"
1099 LPRINT ""
1100 LPRINT"*****************************************************************"
1105 LPRINT"SECTION I: DETAILED VARIABLE COST INFORMATION ON CENTER PIVOT SYSTEM
1110 LPRINT"*****************************************************************"
1150 LPRINT""
1151 LPRINT"                ON A PER ACRE BASIS"
1152 LPRINT"                -------------------"
1155 LPRINT USING "ANNUAL VARIABLE COST = ..... $###,##
#.##";VCPA
1160 LPRINT USING "ANNUAL LABOR COST = ..... $###,##
#.##";LABCOS/AACRE
1162 LPRINT USING "ANNUAL LABOR HOURS = ..... ###,##
#.##";LABHRS/AACRE
1163 LPRINT USING "ANNUAL LABOR HOURS ASSOCIATED WITH OPERATION = ..... ###,##
#.##";LABHR/AACRE
1164 LPRINT USING "ANNUAL LABOR HOURS ASSOCIATED GETTING TO FIELD = .... ###,##
#.##";LABTRAN/AACRE
1165 LPRINT USING "ANNUAL MAINTENANCE COST = ..... $###,##
#.##";MAINT/AACRE
1170 LPRINT USING "ANNUAL FUEL COST = ..... $###,##
#.##";GALD*CE/AACRE
1175 LPRINT USING "ANNUAL OIL COST = ..... $###,##
#.##";GALO*COIL/AACRE
1180 LPRINT USING "ANNUAL COST FROM LOST PRODUCTION = ..... $###,##
#.##";COLP/AACRE
1185 LPRINT USING "ANNUAL COST FROM NEED FOR ADDITIONAL INPUTS =..... $###,##
#.##";BI(I)
```

```
1199 LPRINT ""
1200 LPRINT"*************************************************************************"
1205 LPRINT"*SECTION I: DETAILED FIXED COST INFORMATION ON CENTER PIVOT SYSTEM*"
1210 LPRINT"*************************************************************************"
1215 LPRINT""
1256 LPRINT"                    ON A PER ACRE BASIS"
1257 LPRINT"                    -------------------"
1260 LPRINT USING "TOTAL ANNUAL FIXED COST = ..... $###,##
#.##";AFCPA
1265 LPRINT USING "ANNUALIZED INVESTMENT COST = ..... $###,##
#.##";AIC/AACRE
1270 LPRINT USING "TOTAL INVESTMENT COST = ..... $###,##
#.##";INVESPA
1275 LPRINT USING "COST OF PUMP = ..... $###,##
#.##";PUMPC/AACRE
1280 LPRINT USING "COST OF CEMENT PAD AND GENERATOR = ..... $###,##
#.##";GENPAD/AACRE
1285 LPRINT USING "COST OF BUYING AND BURYING MAIN PIPE = ..... $###,##
#.##";CMP/AACRE
1290 LPRINT USING "COST OF PIVOT ARM =..... $###,##
#.##";CCPPF/AACRE
1295 LPRINT USING "TOTAL COST OF INSURANCE AND TAXES = ..... $###,##
#.##";IRS/AACRE
1299 LPRINT ""
1300 LPRINT"*************************************************************************"
1305 LPRINT"******SECTION III: DETAILS OF THE DESIGNED CENTER PIVOT SYSTEM*****"
1310 LPRINT"*************************************************************************"
1315 LPRINT""
1320 LPRINT USING "LENGTH OF PIVOT IN FEET = ..... #,##
#.##";R
1325 LPRINT USING "GALLONS PER MINUTE = ..... #,##
#.##";GPM
1330 LPRINT USING "DIAMETER OF LATERAL PIPE (inches) = ..... #,##
#.##";D
1335 LPRINT USING "DIAMETER OF MAIN PIPE (inches) = ..... #,##
#.##";SD1
1340 LPRINT USING "LENGTH OF MAIN PIPE (feet) = ..... #,##
#.##";HD+R
1345 LPRINT USING "VELOCITY OF WATER IN MAIN PIPE (feet per second) = ..... #,##
#.##";V3
1350 LPRINT USING "VELOCITY OF WATER IN LATERAL PIPE (feet per second) = .. #,##
#.##";V1
1355 LPRINT USING "FRICTION LOSS PER FOOT IN MAIN PIPE = ..... .####
####";HFM
1360 LPRINT USING "FRICTION LOSS PER FOOT IN LATERAL PIPE = ..... .####
####";HFL
1365 LPRINT USING "PRESSURE LOSS IN POUNDS PER FOOT = ..... #,##
#.##";PSI
1370 LPRINT USING "TOTAL HEAD = ..... #,##
#.##";TH
1375 LPRINT USING "HORSEPOWER OF PUMP = ..... #,##
#.##";HP%
1380 LPRINT USING "HORSEPOWER OF GENERATOR = ..... #,##
#.##";HPG%
1385 LPRINT USING "BRAKE-HORSEPOWER HOURS OF PUMP AND GENERATOR = ..... #,###,##
#.##";HPHR
```

```
1 REM*****************************************************************************
2 REM                    TRAVELING GUN SYSTEM
3 REM                     by: ALAN B. LANIER
4 REM*****************************************************************************
10 REM*****************************************************************************
20 REM
30 REM                      SECTION I: ASIGNING VALUES
40 COUNT = 998
50 REM*****************************************************************************
60 CLS
70 DIM IPH(3),AMC(3),CFL(2),CFM(2),CFS(2),PE(3)
80 DEFSNG N
90 FOR K=1 TO 3
100 REM*****************************************************************************
*
110 REM "IPH" = INCHES PER HOUR; "AMC" = AVAILABLE MOISTURE CONTENT
120 REM "PE" = PUMPING EFFIENCY OF PUMP ; "BI" = ADDITIONAL CROP INPUTS
130 REM "ST$" = SOIL TYPE WHERE "1"= MEDIUM "2"= FINE "3"= COARSE
140 REM*****************************************************************************
*
150 READ IPH(K),AMC(K), PE(K),YPA(K),BI(K),ST$(K)
160 DATA .4,.2,.65,120,59.14,MEDIUM,.3,.133333,.8,100,76.57,FINE,.5,.06667,.9,80
,97.42,COARSE: REM VALUES OF PARAMETERS THAT CHANGE BY SOIL TYPE
170 NEXT K
180 REM "CF(K)"= FRICTION COEFFECIENT; "TOP1"= PCV PIPE "TOP2"= ALUMINUM PIPE
190 CF(1)=120:CF(2)=150:TOP1=2:TOP2=1
200 SD=31:RD=30:REM "SD" = PLANT ROOTS CANNOT PENETRATE PAST THIS DEPTH ********
**********"RD" = MAXIMUM DEPTH CORN ROOTS CAN GROW UNIMPEDED
210 PIE=22/7:TP=.5:REM "PIE"= CONSTANT NEEDED TO CALCULATE THE AREA OF A CIRCLE
********"TP"= PERCENT AVAILABLE MOISTURE WHICH TRIGGERS SYSTEM TO TURN ON
220 REM*****************************************************************************
230 REM
240 REM  SECTION II: RANDOMLY SELECTS VALUES FOR THE MODEL'S PARAMETERS
250 REM
260 REM*****************************************************************************
270 FOR I = 1 TO 3 STEP 1: REM DETERMINES SOIL TYPE PROGRAM WILL ANALYSE
280 IF I = 1 THEN GOTO 310: REM DEFINES "HIGH" WATER HOLDING SOIL
290 IF I = 2 THEN GOTO 320: REM DEFINES "MEDIUM" WATER HOLDING SOIL
300 IF I = 3 THEN GOTO 330: REM DEFINES "LOW" WATER HOLDING SOIL
310 NOD = INT(RND(23)*(88+1)):IF NOD < 1 THEN GOTO 310 ELSE GOTO 340: REM FOR A
********"HIGH" WATER HOLDING SOIL, THE NUMBER OF DAYS THE SYSTEM MUST OPERATE TO
********KEEP THE SOIL MOISTURE AT 50% CAPACITY IS MORE THAN 6 DAYS, BUT LESS
****
320 NOD = INT(RND(31)*(103+1)):IF NOD < 1 THEN GOTO 320 ELSE GOTO 340: REM FOR A
********"MEDIUM" WATER HOLDING SOIL, THE NUMBER OF DAYS THE SYSTEM MUST OPERATE
********TO KEEP THE SOIL MOISTURE AT 50% CAPACITY IS MORE THAN 23 DAYS, BUT LESS
********
330 NOD = INT(RND(83)*(123+1)):IF NOD < 1 THEN GOTO 330: REM FOR A "LOW" WATER
*********HOLDING SOIL, THE NUMBER OF DAYS THE SYSTEM MUST OPERATE TO KEEP THE
*********SOIL MOISTURE AT 50% CAPACITY IS MORE THAN 45 DAYS, BUT LESS THAN 65
340 ACRE = INT(RND(1)*(110+1)):IF ACRE < 10 THEN GOTO 340:REM RANDOM SELECTION
         OF THE NUMBER OF ACRES TO BE IRRIGATED WHERE 0 < ACRES <= 80
350 HD =INT(RND(5)*(15840+1)):IF HD<50 THEN GOTO 350:REM RANDOM SELECTION OF THE
       DISTANCE FROM THE WATER SOURCE TO THE EDGE OF FIELD 50 < HD <= 8000 FEET
360 VD = INT(RND(1)*(300+1)):IF VD<5 THEN GOTO 360:REM RANDOM SELECTION OF THE
       DISTANCE FROM THE TOP OF THE WATER TO THE HIGHEST RISER/EMITTER IN THE
370 CE = RND(12) * 1.5: IF CE < .75 THEN GOTO 370:REM "CE"= COST OF FUEL
380 COIL = CE * 4:REM "COIL"= COST OF OIL FOR LUBRICATING THE PUMP
390 CHP = RND(25) * 225: IF CHP < 125 THEN GOTO 390:REM "CHP"= PER HORSEPOWER
```

```
**************************************************PUMP COST
400 IR = RND(13) * .25: IF IR < .05 THEN GOTO 400:REM "IR"= INTEREST RATE
410 CU = RND(17) * .25: IF CU<.2 THEN GOTO 410:REM PLANT'S CONSUMPTION OF WATER
*********************************************ON A PER DAY BASIS
420 CROPPC = RND(41)*(5.564): IF CROPPC < 1.391 THEN GOTO 420:REM "CROPPC"= SELL
ING*****************************************************************PRICE OF CORN
430 WAGERT = RND(54)* 6.7: IF WAGERT < 3.35 THEN GOTO 430:REM "WAGERT"= HOURLY
*********************************************************WAGE RATE FOR LABOR
440 HOURS = RND(31)*23: IF HOURS < 18 THEN GOTO 440:REM "HOURS"= OPERATING HOURS
*************************************************PLUS MOVING TIME PER DAY
450 REM*************************************************************************
460 REM
470 REM SECTION III: SYSTEM DESIGN, OPERATING TIME AND WATER FLOW REQUIREMENTS
480 REM
490 REM*************************************************************************
500 SQFT = (ACRE*43560!)^.5:REM ASSUMES FIELD IS SQUARE AND CALCULATES ITS    **
*****************************WIDTH AND LENGTH
510 X = 1!*SQFT: Y = 1!*SQFT:REM "X"= WIDTH; "Y"=LENGTH
520 IF Y < 1300 THEN Y1=Y: Y2=1 ELSE Y1=Y/2 :Y2=2:REM SINCE TRAVELING GUN'S   **
******MAXIMUM RUN IS 1300 FEET, FIELD IS HALVED WHICH DOUBLES THE RUNS
530 IF SD < RD THEN MIN = SD ELSE MIN = RD:REM DETERMINES THE DEPTH ROOTS CAN **
******************************************GROW
540 DPI = (AMC(I)*MIN*TP)/CU:REM DAYS PER IRRIGATION CYCLE
550 HPI = DPI*(HOURS-((ACRE*.2)/DPI)):REM DETERMINES OPERATING HOURS OF ONE  ***
*************************************IRRIGATION CYCLE
560 WAI = (DPI*CU)/.75: REM WATER APPLIED PER IRRIGATION
570 GPM = ((453/HPI)*(ACRE*WAI)):REM DETERMINES THE WATER FLOW NECESSARY TO ****
*********************************MEET THE PLANT'S WATER REQUIREMENTS
580 REM*************************************************************************
590 REM DECISION POINT IN THE ITERATION PROCESS WHERE THE OPERATING TIME OF   **
********THE SYSTEM FITS WITHIN 99.75% AND 100.25% OF THE TIME LIMIT
600 REM*************************************************************************
610 LS = 175:REM STARTS WITH LENGTH OF SPRAY AT 125 FEET
620 NUMR = (X*Y2)/(LS*2):REM DETERMINES THE NUMBER OF RUNS NECESSARY TO COVER **
******************THE FIELD**NOTE: WHEN "Y2"= 2 THE NUMBER OF RUNS ARE DOUBLED
630 LRUN = Y1-(LS*2):REM DETERMINES THE DISTANCE THE GUN MUST TRAVEL BY      **
*ASSUMING THE GUN WILL START AND STOP WHEN THE SPRAY TOUCHES THE EDGE OF FIELD
640 FTHR = (LS*2)/(WAI/IPH(I)):REM SPEED OF TRAVELER
650 TPR = (LRUN/FTHR)+((4.5/3)*(WAI/IPH(I))):REM DETERMINES THE TIME NECESSARY**
*TO COMPLETE A RUN (GUN STATIONARY AT BOTH ENDS FOR 4.5/3 THE TIME ITTAKES TO **
*REPLACE THE WATER
660 LABHR = ((Y1*LS*2)/43560!)*.2:REM SET-UP TIME FOR EACH RUN
670 TPI = (TPR+LABHR)*NUMR: REM OPERATING AND SET-UP TIME PER RUN
680 IF TPI > DPI*HOURS*1.0025 THEN LS = LS*1.0025:GOTO 620: REM IF THE TIME ****
*********TO OPERATE GUN IS MORE THAN THE TIME AVAILABLE, LENGTH OF SPRAY IS ****
*********INCREASED 0.25%
690 IF TPI < DPI*HOURS*.9975 THEN LS = LS*.9975:GOTO 620:REM IF THE TIME TO ****
********OPERATE THE GUN IS LEES THAN THE TIME AVAILABLE, LENGTH OF SPRAY IS ****
********DECREASED 0.25%
700 REM*****************ITERATEION STOPS*************************************
710 LABTRAN = .5 * NUMR: REM TRANSPORTING 1 PERSON TO AND FROM THE FIELD      **
************** ASSUMING 15 MINUTES EACH WAY
720 AACRE = ((Y1*Y2)*((NUMR/Y2)*(LS*2)))/43560!:REM ACTUAL ACRES IRRIGATED
730 APG = ((LS^2)*PIE)/43560!:REM ACRES IRRIGATED BY THE STATIONARY GUN
740 ACREINCH = APG*IPH(I):REM ACRE-INCHES BEING APPLIED
750 GPM1 = ACREINCH*453:REM ACTUAL GALLONS PER MINUTE
760 REM*************************************************************************
770 REM
780 REM   SECTION IV: SIZING PIPE, COSTING PIPE, AND DETERMINIING HORSEPOWER
790 REM
```

```
800 REM************************************************************************
810 REM********TABLE OF SELECTIONS FOR THE DIFFERENT SIZE GUNS WHERE***
820 REM "A4"= CONVERTING PRESSURE INTO POUNDS OF HEAD
830 REM "D" = DIAMETER OF FLEXIBLE HOSE
840 IF GPM1 <= 200 THEN A4=173:D=3:GOTO 900
850 IF GPM1 <= 300 THEN A4=185:D=3.5:GOTO 900
860 IF GPM1 <= 400 THEN A4=196.4:D=4:GOTO 900
870 IF GPM1 <= 500 THEN A4=208:D=4.5:GOTO 900
880 IF GPM1 > 500 THEN A4=219:D=5:GOTO 900
890 REM ******A4 IS A CONVERSION OF PRESSURE INTO TOTAL HEAD ***
900 V1 = (.408*GPM1)/(D^2): REM VELOCITY OF WATER IN FLEXIBLE HOSE
910 REM************************************************************************
920 REM DETERMINES VELOCITY IN MAIN PIPE WHERE VELOCITY CAN NOT EXCEED 5'/SEC.
930 REM************************************************************************
940 SD1=INT(D+.4999)-1
950 IF SD1<= 3 THEN SD1=SD1+1 ELSE SD1=SD1+2:REM DEFINES DIAMETER IN MAIN PIPE
960 V3=(.408*GPM1)/(SD1^2): REM VELOCITY OF WATER IN MAIN PIPE
970 IF V3>6 THEN IF SD1=8 THEN GOTO 990 ELSE GOTO 950
980 REM************************************************************************
990 HFL = (((2.3*V1)/((1.318*(180))*((D/12)^.63)))^1.852):REM FRICTION LOSS  ***
**************************************************IN FLEXIBLE HOSE (PER FOOT)
1000 HFM = (((2.3*V3)/((1.318*(150))*((SD1/12)^.63)))^1.852):REM FRICTION LOSS
*****************************************************************IN MAIN (PER FOOT)
1010 TH = (VD+10) + (HFL*(LRUN+LS)) + (HFM*(HD+X-LS)) + A4:REM TOTAL HEAD
1020 HP% = (TH*GPM1)/(3960*.8) + .5: REM HORSEPOWER OF PUMP
1030 REM************************************************************************
1040 REM
1050 REM       SECTION V: COMPUTING VARIABLE COST FOR THE IRRIGATION SYSTEM
1060 REM
1070 REM************************************************************************
1080 CPS = NOD/DPI:REM CYCLES PER SEASON
1090 HPHR = HP%*TPR*NUMR*CPS:REM BRAKE-HORSEPOWER-HOURS PER SEASON
1100 GALD = HPHR/14.6:REM GALLONS OF FUEL CONSUMED PER IRRIGATION
1110 GALO = HPHR/3000:REM GALLONS OF OIL CONSUMED PER IRRIGATION
1120 LABHRS = ((LABHR*NUMR)+LABTRAN)*CPS
1130 LABCOS = LABHRS*WAGERT:REM LABOR COST PER IRRIGATION SEASON
1140 MAINT = .0019*HPHR: REM MAINTENANCE COST PER IRRIGATION ON AVERAGE
1150 COLP = (YPA(I)*CROPPC)*.04:REM COST OF LOST PRODUCTION DUE TO TRAVELING GUN
1160 VC = (GALD*CE)+(GALO*COIL)+MAINT+LABCOS+((COLP+BI(I))*AACRE): REM TOTAL   *
*********************************************VARIABLE COST PER IRRIGATION SEASON
1170 VCPA = (VC/AACRE): REM VARIABLE COST PER ACRE
1180 REM************************************************************************
1190 REM
1200 REM SECTION VI: COMPUTING FIXED COST FOR THE IRRIGATION SYSTEM************
1210 REM
1220 REM************************************************************************
1230 COST = GPM1*40:REM COST OF FLEXIBLE HOSE & TRAVELING GUN PLATFORM
1240 REM DETERMINING THE COST OF MAIN PIPE BASED ON ITS DIAMETER
1250 IF SD1=3 THEN CM=2 :GOTO 1290
1260 IF SD1=4 THEN CM=2.5:GOTO 1290
1270 IF SD1<=6 THEN CM=3 :GOTO 1290
1280 IF SD1<=8 THEN CM=4.25 ELSE CM=6.25:REM SELECTS THE CORRECT PRICE OF PVC  *
*****************************************PIPE
1290 CMP = CM*(HD+X-LS): REM TOTAL COST OF BUYING PVC PIPE FOR MAIN
1300 PUMPC = CHP*HP%:REM COST OF PUMP
1310 TVC = INT(NUMR+.99999)*10*SD1:REM COST OF HYDRANTS TO CONNECT MAIN PIPE TO*
********** FLEXIBLE HOSE
1320 INVES = COST+PUMPC+CMP+TVC: REM INVESTMENT COST
1330 INVESPA = INVES/AACRE:REM TOTAL INVESTMENT COST PER ACRE
1340 IRS = INVES*.02:REM ANNUAL COST OF INSURANCE AND TAXES
```

```
1350 CRF = IR/(1-(1+IR)^(0-15)):REM "CFR"= CAPITAL RECOVERY FACTOR TO ANNUALIZE
 ********************************THE INVESTMENT COST OF SYSTEM
1360 AIC = INVES*CRF:REM ANNUALIZED INVESTMENT COST
1370 AFC = (INVES*CRF)+IRS:REM ANNUAL FIXED COST
1380 AFCPA = AFC/AACRE:REM ANNUAL FIXED COST PER ACRE
1390 ATC = AFC + VC: REM ANNUAL TOTAL COST
1400 ATCPA = ATC/AACRE:REM ANNUAL TOTAL COST PER ACRE
1405 BEY=ATCPA/CROPPC
1410 GOTO 10000
1420 REM*************************************************************************
1430 LPRINT"*************************************************************************"
1440 LPRINT"      DETAILED DIAGNOSTIC PRINTOUT FOR TRAVELING GUN SYSTEM"
1450 LPRINT"*************************************************************************"
1460 LPRINT""
1470 LPRINT"*************************************************************************"
1480 LPRINT USING "TOTAL ANNUAL COST OF TRAVELING GUN = ..... $##,###.#
#";ATC
1490 LPRINT USING "TOTAL ANNUAL PER ACRE COST OF TRAVELING GUN = ..... $###.#
#";ATCPA
1500 LPRINT"*************************************************************************"
1510 LPRINT ""
1520 LPRINT USING"TOTAL ACRES IRRIGATED = ..... ###.#"
;AACRE
1530 LPRINT USING"LENGTH AND WIDTH OF FIELD = ..... ###.#"
;X
1540 LPRINT USING "WATER HOLDING CAPACITY (in. of water per in. of soil) = #.###
";AMC(I)
1550 LPRINT USING "NUMBER OF DAYS SYSTEM WILL OPERATE DURING THE YEAR =... ###.#
";NOD
1560 LPRINT USING "SOIL UPTAKE RATE (INCHES PER HOUR)   = ..... #.###
";IPH(I)
1570 LPRINT USING "VERTICAL DISTANCE IN FEET = ..... ###.#
";VD
1580 LPRINT USING "HORIZONTAL DISTANCE = ..... ####.#
";HD
1590 LPRINT USING "PERCENT OF AVAILABLE WATER TO TRIGGER IRRIGATION = ... ##.###
%";TP*100
1600 LPRINT "SOIL TYPE = .....";ST$(I)
1610 LPRINT USING "PLANT'S DAILY WATER REQUIREMENTS IN INCHES = ..... #.###
";CU
1620 LPRINT ""
1630 LPRINT USING "COST OF FUEL IN DOLLARS PER GALLON =..... $#.###
";CE
1640 LPRINT USING "COST OF OIL IN DOLLARS PER GALLON = ..... $#.###
";COIL
1650 LPRINT USING "HORSEPOWER COST ON A COST PER HORSEPOWER BASIS =..... $###.#
";CHP
1660 LPRINT USING "SELLING PRICE PER BUSHEL OF CORN = ..... $#.###
";CROPPC
1670 LPRINT USING "HOURLY WAGE RATE FOR LABOR = ..... $#.###
";WAGERT
1680 LPRINT USING "COST OF CAPITAL (INTEREST RATE) = .....  ##.##%
";IR*100
1690 LPRINT USING "YIELD PER ACRE WITHOUT IRRIGATION = .....   ###.#
";YPA(I)
1700 LPRINT USING "ADDITIONAL INPUTS WITH IRRIGATION (per acre) = ..... $##.##
";BI(I)
1710 LPRINT"*************************************************************************
****"
1720 LPRINT "SECTION 2: PARAMETERS IMPACTING DESIGN OF TRAVELING GUN SYSTEM"
```

```
1730 LPRINT"**********************************************************************
****"
1740 LPRINT""
1750 LPRINT USING "DAYS PER IRRIGATION CYCLE = ............................. #
#.##";DPI
1760 LPRINT USING "WATER APPLIED PER IRRIGATION CYCLE (in inches) = ..........
#.##";WAI
1770 LPRINT USING "RADIUS OF WATER SPRAY (in feet) = ....................... ##
#.##";LS
1780 LPRINT USING "NUMBER OF IRRIGATION RUNS PER CYCLE = ................... ##
#.##";NUMR
1790 LPRINT USING "LENGTH AND WIDTH OF FIELD = ............................ #,##
#.##";X
1800 LPRINT USING "LENGTH OF ONE IRRIGATION RUN = ......................... ####
#.##";LRUN
1810 LPRINT USING "SPEED OF TRAVELING GUN (in feet per hour) = ............ ####
#.##";FTHR
1820 LPRINT USING "TIME SYSTEM OPERATES DURING ONE RUN ( in hours ) = ..... ####
#.##";TPR
1830 LPRINT USING "TIME TO MOVE SYSTEM BETWEEN RUNS ( in hours ) = ........ ####
#.##";LABHR
1840 LPRINT USING "TIME PER IRRIGATION CYCLE ( in hours ) = ............... ####
#.##";TPI
1850 LPRINT USING "TIME NEEDED TO OPERATE AND MOVE SYSTEM EACH DAY (in hours) =
##.#";(TPR*NUMR)/DPI
1860 LPRINT USING "ACRES BEING IRRIGATED AT ANY MOMENT BY GUN = .............. #
##.#";APG
1870 LPRINT USING "ACRE-INCHES OF WATER BEING APPLIED = ..................... #
##.#";ACREINCH
1880 LPRINT USING "GALLONS PER MINUTE = ..................................... #,#
##.#";GPM1
1890 LPRINT USING "POUNDS OF HEAD DUE TO WATER PRESSURE OF SYSTEM = ........ #,#
##.#";A4
1900 LPRINT USING "TOTAL HEAD OF SYSTEM = ................................... #,#
##.#";TH
1910 LPRINT USING "DIAMETER OF FLEXIBLE HOSE = ..............................
##.#";D
1920 LPRINT USING "DIAMETER OF MAIN PIPE = ..................................
##.#";SD1
1930 LPRINT USING "VELOCITY OF WATER IN FLEXIBLE HOSE ( in feet per second ) =
##.#";V1
1940 LPRINT USING "VELOCITY OF WATER IN MAIN PIPE ( in feet per second ) = ...
##.#";V3
1950 LPRINT USING "FRICTION LOSS IN FLEXIBLE HOSE ( per foot ) =.......... #.###
####";HFL
1960 LPRINT USING "FRICTION LOSS IN MAIN PIPE ( per foot ) =.............. #.###
####";HFM
1970 LPRINT USING "HORSEPOWER OF SYSTEM = ................................... ##
#.##";HP%
1980 REM LPRINT CHR$(12);"":REM PAGE EJECT COMMAND
1990 LPRINT"**********************************************************************
2000 LPRINT"   SECTION 3: ANNUAL VARIABLE COST OF TRAVELING GUN SYSTEM
2010 LPRINT"**********************************************************************
2020 LPRINT"                                  "
2030 LPRINT"                ON A PER ACRE BASIS"
2040 LPRINT"                --------------------"
2050 LPRINT USING "ANNUAL VARIABLE COST = ............................... $###,##
#.##";VCPA
2060 LPRINT USING "ANNUAL LABOR COST = .................................. $###,##
#.##";LABCOS/AACRE
```

```
2070 LPRINT USING "ANNUAL LABOR HOURS FOR OPERATING SYSTEM = .....  ###,
#.##";(LABHR*NUMR*CPS)/AACRE
2080 LPRINT USING "ANNUAL LABOR HOURS TO GET TO AND FROM FIELD = .....  ###,
#.##";(LABTRAN*NUMR*CPS)/AACRE
2090 LPRINT USING "ANNUAL LABOR HOURS = .....  ###,
#.##";LABHRS/AACRE
2100 LPRINT USING "ANNUAL MAINTENANCE COST = ..... $###,
#.##";MAINT/AACRE
2110 LPRINT USING "ANNUAL FUEL COST = ..... $###,
#.##";GALD*CE/AACRE
2120 LPRINT USING "ANNUAL OIL COST = ..... $###,
#.##";GALO*COIL/AACRE
2130 LPRINT USING "ANNUAL COST FROM LOST PRODUCTION = ..... $###,
#.##";COLP
2140 LPRINT USING "ANNUAL COST FROM NEED FOR ADDITIONAL INPUTS =..... $###,
#.##";BI(I)
2150 LPRINT ""
2160 LPRINT"*************************************************************************
2170 LPRINT"   SECTION 4: ANNUAL FIXED COST FOR A TRAVELING GUN SYSTEM"
2180 LPRINT"*************************************************************************
2190 LPRINT""
2200 LPRINT"                          _________________________"
2210 LPRINT"                           ON A PER ACRE BASIS"
2220 LPRINT"                          ----------------------"
2230 LPRINT USING "TOTAL ANNUAL FIXED COST = ..... $###,
#.##";AFCPA
2240 LPRINT USING "ANNUALIZED INVESTMENT COST = ..... $###,
#.##";AIC/AACRE
2250 LPRINT USING "TOTAL INVESTMENT COST = ..... $###,
#.##";INVESPA
2260 LPRINT USING "COST OF PUMP = ..... $###,
#.##";PUMPC/AACRE
2270 LPRINT USING "COST OF BUYING AND BURYING MAIN PIPE = ..... $###,
#.##";CMP/AACRE
2280 LPRINT USING "COST OF GUN, PLATFORM, AND FLEXIBLE HOSE = ..... $###,
#.##";COST/AACRE
2290 LPRINT USING "TOTAL COST OF INSURANCE AND TAXES = ..... $###,
#.##";IRS/AACRE
```

```
1 REM*************************************************************************
2 REM             PORTABLE PIPE AND BIG FIXED GUN SYSTEMS
3 REM                  by: ALAN B. LANIER
4 REM*************************************************************************
10 REM************************************************************************
20 REM*****************SECTION I: ASSIGNED VALUES ****************************
30 REM************************************************************************
40 CLS
50 DIM IPH(3),AMC(3),CFL(2),CFM(2),CFS(2),PE(3)
60 DEFSNG N
70 FOR K=1 TO 3
80 READ IPH(K),AMC(K), PE(K),YPA(K),BI(K),ST$(K)
90 DATA .4,.2,.65,120,59.14,MEDIUM,.3,.133333,.8,100,76.57,FINE,.5,.06667,.9,80,
97.42,COARSE
100 NEXT K
110 REM "CF"= FRICTION COEFFICIENT; "TOP1"= ALUMINUM PIPE; "TOP2"= PVC PIPE
120 CF(1)=120:CF(2)=150:TOP1=1:TOP2=2
130 SD=31:RD=30:REM "SD"= PLANT'S ROOTS CAN NOT PENETRATE THIS DEPTH************
**********************"RD"= MAXIMUN DEPTH CORN ROOTS CAN GROW
140 CTV1=120: CTV2=140
150 REM "CTV1"= T-VALVE COST FOR SUBMAIN LESS THAN OR EQUAL TO 4" IN DIAMETER***
160 REM "CTV2"= T-VALVE COST FOR SUBMAIN GREATER THAN 4" IN DIAMETER************
161 TOS= 1:REM RND(6)*2: IF TOS < 1 THEN TOS=1 ELSE TOS=2:REM RANDOMLY SELECTING
 A    **************PORTABLE PIPE OR BIG FIXED GUN SYSTEM
180 REM************************************************************************
190 REM
200 REM************************************************************************
210 REM**SECTION II: RANDOM SELECTS VALUES FOR THE MODEL'S PARAMETERS************
220 REM************************************************************************
230 FOR I = 1 TO 3 STEP 1: REM DETERMINES SOIL TYPE PROGRAM WILL ANALYSE
240 IF I = 1 THEN GOTO 270: REM DEFINES "HIGH" WATER HOLDING SOIL
250 IF I = 2 THEN GOTO 280: REM DEFINES "MEDIUM" WATER HOLDING SOIL
260 IF I = 3 THEN GOTO 290: REM DEFINES "LOW" WATER HOLDING SOIL
270 NOD = INT(RND(23)*(88+1)):IF NOD < 1 THEN GOTO 270 ELSE GOTO 300: REM FOR A
********"HIGH" WATER HOLDING SOIL, THE NUMBER OF DAYS THE SYSTEM MUST OPERATE TO
********KEEP THE SOIL MOISTURE AT 50% CAPACITY IS MORE THAN 6 DAYS, BUT LESS
280 NOD = INT(RND(31)*(103+1)):IF NOD < 1 THEN GOTO 280 ELSE GOTO 300: REM FOR A
********"MEDIUM" WATER HOLDING SOIL, THE NUMBER OF DAYS THE SYSTEM MUST OPERATE
********TO KEEP THE SOIL MOISTURE AT 50% CAPACITY IS MORE THAN 23 DAYS, BUT LESS
290 NOD = INT(RND(83)*(123+1)):IF NOD < 1 THEN GOTO 290: REM FOR A "LOW" WATER
********HOLDING SOIL, THE NUMBER OF DAYS THE SYSTEM MUST OPERATE TO KEEP THE
********SOIL MOISTURE AT 50% CAPACITY IS MORE THAN 45 DAYS, BUT LESS THAN 65
300 ACRE = INT(RND(1)*(80+1)):IF ACRE < 1 THEN GOTO 300:REM RANDOM SELECTION OF
       THE NUMBER OF ACRES TO BE IRRIGATED WHERE 0 < ACRES <= 80
320 IF TOS=1 THEN RADIUS=30:CRS=35:PRESS=115.5:LAB=1 ELSE RADIUS=90:CRS=800:PRES
S=173.25:LAB=.75:REM"TOS"=1 ->PORTABLE PIPE SYSTEM "TOS"=2->BIG FIXED GUN SYSTEM
321 REM "CRS"= COST OF RISER & SPRINKLER "RADIUS"= DISTANCE OF WATER STREAM FROM
******* GUN "PRESS"= INCREASE IN HEAD DUE TO THE PRESSURE OF SYSTEM
330 HD= INT(RND(5)*(15840+1)):IF HD<50 THEN GOTO 330:REM RANDOM SELECTION OF THE
       DISTANCE FROM THE WATER SOURCE TO THE EDGE OF FIELD 50 < HD <= 8000 FEET
340 VD = INT(RND(1)*(300+1)):IF VD<5 THEN GOTO 340:REM RANDOM SELECTION OF THE
       DISTANCE FROM THE TOP OF THE WATER TO THE HIGHEST RISER/EMITTER IN THE
350 CE = RND(12) * 1.5: IF CE < .75 THEN GOTO 350
360 COIL = CE * 4
370 CHP = RND(25) * 225: IF CHP < 125 THEN GOTO 370
380 IR =  RND(13) * .25: IF IR < .05 THEN GOTO 380
390 CU = RND(17) * .25: IF CU<.2 THEN GOTO 390
400 CROPPC = RND(41)*(5.564): IF CROPPC < 1.391 THEN GOTO 400
410 WAGERT = RND(54)* 6.7: IF WAGERT < 3.35 THEN GOTO 410
```

```
420 TP= .5:REM RND(99) * .7:IF TP<.5 THEN 420:REM AVAILABLE MOISTURE CONTENT OF
SOIL  ********************************** THAT TRIGGERS THE SYSTEM TO START OPE
RATING
430 REM*************************************************************************
440 REM
450 REM**SECTION III: SYSTEM DESIGN, OPERATING TIME AND WATER FLOW REQUIREMENTS*
460 REM
470 REM*************************************************************************
480 SQFT=(ACRE*43260!)^.5:REM ASSUMES SQUARE FIELD & CALCULATES SQUARE FOOTAGE
490 X=1!*SQFT:Y=1!*SQFT:REM "X"= WIDTH OF FIELD &00"Y"= LENGTH OF FIELD
500 IF SD<RD THEN MIN=SD ELSE MIN=RD:REM SELECTS DEPTH OF ROOT GROWTH
510 DPI = (AMC(I)*MIN*(1-TP))/CU:REM DAYS PER IRRIGATION
520 WAI = DPI*CU/.7: REM CALCULATES WATER APPLIED PER IRRIGATION
530 APG = ((RADIUS^2)*(22/7))/43560!:REM ACRES IRRIGATED PER GUN
540 HOURS = 18: HPI = DPI*HOURS: OHPS = WAI/IPH(I): REM OPERATING HOURS PER
********IRRIGATED CYCLE = "HPI" AND PER SETTING = "OHPS"
550 NOSPD= HOURS/OHPS: REM NUMBER OF SETTINGS PER DAY
560 REM*************************************************************************
570 REM ADDING GUNS UNTIL ALL ACRES CAN BE IRRIGATED WITHIN TIME CONSTRAINT
580 REM*************************************************************************
590 GUN = 0
600 GUN = GUN +1: REM ADDING GUNS TO THE SYSTEM UNTIL THE TIME COSTRAINT IS
********SATISFIED
610 IF (DPI*NOSPD*APG*GUN)/ACRE <= 1 THEN GOTO 600:REM DETERMINE IF THE SYSTEM
********IS COVERING ENOUGH ACREAGE TO FULFILL TIME CONSTRAINT
620 REM*************************************************************************
630 AACRE = NOSPD*GUN*APG*DPI: IF AACRE = ACRE THEN GOTO 740:REM CALCULATES
********ACTUAL ACRES IRRIGATED AND IF EQUAL TO FIELD SIZE GETS OUT OF LOOP
640 REM*************************************************************************
650 REM REDUCING OPERATING HOURS UNTIL ACRES IRRIGATED EQUALS SIZE OF FIELD
660 REM*************************************************************************
670 HOURS = HOURS*.995:NOSPD = HOURS/OHPS:AACRE = NOSPD*GUN*APG*DPI:REM
********DECREASES OPERATING TIME BY .5% AND RECALCULATES ALL RELEVANT VARIABLES
680 IF AACRE > ACRE THEN GOTO 670
690 REM*************************************************************************
700 LABHR = NOSPD*GUN*APG*LAB:REM LABOR-HOURS REQUIRED TO MOVE SYSTEM EACH DAY
710 LABTRAN = 4*(NOSPD*.5):REM DAILY LABOR-TIME GETTING 4 MEN TO AND FROM FIELD
************************** (15 MINUTES ONE WAY)
720 LABHRS = LABHR+LABTRAN
730 THRPD = HOURS+(LABHR/4):REM TOTAL HOURS NEEDED TO OPERATE SYSTEM IN ONE DAY
740 LL1 = (X/2)-RADIUS:REM CALCULATE THE LENGTH OF LATERAL PIPE FOR ONE LATERAL
750 REM**DETERMINING THE NUMBER OF LATERALS BY DIVIDING THE LENGTH OF PIPE
*********NEEDED TO REACH ALL GUNS BY THE LENGTH OF ONE RUN
760 IF TOS=1 THEN LL1A= ((GUN*2)-1)*30 ELSE LL1A= ((GUN*6)-3)*30:REM THE LENGTH
**************************** OF PIPE ASSOCIATED WITH THE GUNS-> SYSTEM DEPENDENT
770 IF LL1A>LL1 THEN NOL=LL1A/LL1 ELSE NOL=1: REM DETERMINING NUMBER OF LATERALS
******** ASSOCIATED WITH EACH SETTING BY DECIDING IF MORE THAN ONE RUN IS NEEDED
780 REM*************************************************************************
790 LS% = LL1/30*NOL:TLL = LS%*30:REM SECTIONS AND LENGTH OF LATERAL PIPE
800 SS% = (Y-RADIUS)/30 : REM CALCULATES THE NUMBER OF SUBMAIN SECTIONS
810 LSP= SS%*30:REM TOTAL LENGTH OF SUBMAIN PIPE
820 MP = HD:REM LENGTH OF MAIN PIPE FROM WATER SOURCE TO FIELD'S EDGE
830 AIPH = GUN*APG*IPH(I):REM ACRE-INCHES PER SETTING-HOUR
840 GPM = AIPH*453:REM CONVERT ACRE-INCHES PER HOUR INTO GALLONS PER MINUTE
850 REM*************************************************************************
860 REM
870 REM   SECTION IV: SIZING PIPE, COSTING PIPE AND DETERMINING HORSEPOWER
880 REM
890 REM*************************************************************************
900 D=2: REM STARTING PROCESS FOR LATERAL PIPE
```

```
910 D=D+1
920 IF NOL=1 THEN V1= (.408*GPM)/D^2 ELSE V1= (.408*(GPM/NOL))/D^2:REM VELOCITY
****OF WATER IN LATERAL AND COMPENSATING FOR THE NUMBER OF LATERALS
930 IF V1>7.5 THEN GOTO 910:REM SIZING CONSTRAINT-> VELOCITY 7.5 FT. PER SEC OR
LESS
940 DS=D-1:REM STARTING PROCESS FOR SUBMAIN PIPE AND MAIN PIPE
950 DS=DS+1:SD1=DS
960 V2 = (.408*GPM)/DS^2: REM CALCULATE VELOCITY OF WATER IN SUBMAIN
970 V3=V2:IF V2>6! THEN GOTO 950:REM SIZING CONSTRAINT->LESS THAN 6' PER SECOND
980 REM CALCULATING FRICTION LOSS IN LATERAL BY FACTORING IN THE NUMBER OF GUNS
******* ON A LATERAL AS WATER FLOW IS REDUCED AFTER MOVING PAST A GUN
990 IF GUN/NOL < 2 THEN FACTOR = 1!:GOTO 1010
1000 IF GUN/NOL < 3 THEN FACTOR = .5:GOTO 1010 ELSE FACTOR = .333
1010 HFL = (((2.39*V1)/((1.318*CF(TOP1))*((D/12)^.63)))^1.852)*FACTOR :REM
********* CALCULATES FRICTION LOSS IN LATERAL (PER FOOT)
1020 HFS = (((2.39*V2)/((1.318*CF(TOP1))*((SD/12)^.63)))^1.852): REM CALCULATES
FRICTION LOSS IN SUBMAIN (PER FOOT)
1030 REM 740-780-> FRICTION LOSS FOR MAIN PIPE AS PVC PIPE HAS LIMITED CHOICES
1040 IF SD1=5 THEN SD1=6
1050 IF SD1=6 THEN V3=(.408*GPM)/(SD1^2)
1060 IF SD1=7 THEN SD1=8
1070 IF SD1=8 THEN V3 =(.408*GPM)/(SD1^2)
1080 HFM = (((2.39*V3)/((1.318*CF(TOP2))*((SD/12)^.63)))^1.852) : REM CALCULATES
**** FRICTION LOSS IN MAIN ON A PER FOOT BASIS
1090 TF1 = (HFL * (LL1A)): REM TOTAL FRICTION LOSS IN LATERAL
1100 TF2 = (HFS*LSP): REM TOTAL FRICTION LOSS IN SUBMAIN
1110 TF3 = (HFM*HD):REM TOTAL FICTION LOSS IN MAIN
1120 TFL = TF1 + TF2 + TF3:REM TOTAL FRICTION LOSS IN SYSTEM
1130 TH = TFL + (VD+10) + PRESS: REM TOTAL HEAD
1140 HP% = ((TH*GPM)/(3960*.8))+.5:REM HORSEPOWER WITH 80.0% ENGINE EFFICIENCY
1150 IF D=2 THEN CLP=1.29
1160 IF D=3 THEN CLP=1.77
1170 IF D=4 THEN CLP=2.27
1180 IF D=5 THEN CLP=2.89
1190 IF D=6 THEN CLP=3.86
1200 IF D=7 THEN CLP=5.73
1210 IF D=8 THEN CLP=7.15
1220 IF D>8 THEN STOP:REM STOP SYSTEM FROM GETTING TOO LARGE
1230 IF DS=3 THEN CS=1.77
1240 IF DS=4 THEN CS=2.27
1250 IF DS=5 THEN CS=2.89
1260 IF DS=6 THEN CS=3.86
1270 IF DS=7 THEN CS=5.73
1280 IF DS=8 THEN CS=7.15
1290 IF DS<4 THEN CTV=120 ELSE CTV=140: REM "CTV"= COST OF T-VALVES AND IS
************************************ DEPENDENT ON THE DIAMETER OF SUBMAIN PIPE
1300 IF DS>8 THEN STOP:REM STOP SYSTEM FROM GETTING TOO LARGE
1310 IF SD1=2 THEN CM=1.5
1320 IF SD1=3 THEN CM=2!
1330 IF SD1=4 THEN CM=2.5
1340 IF SD1=6 THEN CM=3!
1350 IF SD1=8 THEN CM=4.25
1360 IF SD1>8 THEN STOP:REM STOP SYSTEM FROM GETTING TOO LARGE
1370 REM*************************************************************************
1380 REM
1390 REM        SECTION V: COMPUTING VARIABLE COST OF SYSTEM
1400 REM
1410 REM*************************************************************************
1420 HPHR = OHPS*NOSPD*HP%*NOD:REM BRAKE-HORSEPOWER HOURS PER SEASON
1430 GALD = HPHR/14.6*CE:REM ANNUAL COST OF FUEL CONSUMED EACH YEAR
```

```
1440 GALO = HPHR/3000*COIL:REM ANNUAL COST OF OIL
1450 MAINT = .0019*HPHR:REM MAINTENANCE COST PER YEAR
1460 LABCOS = LABHR*WAGERT*NOD:REM ANNUAL LABOR COST
1470 ACAI = BI(I)*AACRE:REM ADDED COST OF ADDITIONAL INPUTS PER ACRE
1480 COLP = YPA(I)*CROPPC*.01*AACRE:REM COST OF LOST LAND PRODUCTION FROM LOST
********** LAND ON A PER ACRE BASIS
1490 VC = GALD+GALO+MAINT+LABCOS+ACAI+COLP:REM ANNUAL VARIABLE COST
1500 VCPA = VC/AACRE:REM ANNUAL VARIABLE COST PER ACRE
1510 REM*************************************************************************
1520 REM
1530 REM       SECTION VI: COMPUTING FIXED COST OF IRRIGATION SYSTEM
1540 REM
1550 REM*************************************************************************
1560 CMP = CM*HD:REM TOTAL COST OF BUYING AND BURYING MAIN PIPE
1570 CSP = CS*LSP: REM TOTAL COST OF SUBMAIN PIPE
1580 IF NOL=1 THEN CL=CLP*LL1 ELSE CL=CLP*LL1A:REM TOTAL COST OF LATERAL PIPE
1590 TRG = CRS*GUN: REM TOTAL COST OF RISER AND SPRINKLER
1595 TVC = INT(NOL+.99999)*CTV:REM TOTAL COST OF ALL T-VALVES
1600 PUMPC = HP%*CHP: REM TOTAL COST OF PUMP
1610 INVES = CMP+CSP+CL+TRG+PUMPC+TVC:REM CALCULATES THE TOTAL COST OF SYSTEM
1620 CRF = IR/(1-(1+IR)^(0-15)): REM CALCULATES CAPITAL RECOVERY FACTOR
1630 ACR = INVES*CRF: REM CALCULATES ANNUAL CAPITAL RECOVERY
1640 IRS = INVES*.02: REM CALCULATES ANNUAL COST OF INSURANCE AND TAXES
1650 AFC = (ACR+IRS): REM ANNUAL FIXED COST OF SYSTEM OVER 10 YEARS
1660 AFCPA = AFC/AACRE: REM AVERAGE FIXED COST PER ACRE
1670 ATC = AFC+VC:REM ANNUAL TOTAL COST PER SEASON
1680 ATCPA = ATC/AACRE: REM ANNUAL AVERAGE TOTAL COST PER ACRE
1682 BEY = ATCPA/CROPPC
1685 GOTO 10000
1690 REM*************************************************************************
1700 LPRINT"*************************************************************************"
1710 LPRINT"  DETAILED DIAGNOSTIC PRINTOUT FOR A PORTABLE HAND MOVED SYSTEM"
1720 LPRINT"*************************************************************************"
1725 IF TOS=1 THEN LPRINT "                PORTABLE PIPE SYSTEM                  "
 ELSE LPRINT "                  BIG FIXED GUN SYSTEM                    "
1730 LPRINT""
1740 LPRINT"*************************************************************************"
1750 LPRINT USING "TOTAL ANNUAL COST OF SYSTEM = ..................... $##,###.#
#";ATC
1760 LPRINT USING "TOTAL ANNUAL PER ACRE COST OF SYSTEM = ............... $###.#
#";ATCPA
1770 LPRINT"*************************************************************************"
1780 LPRINT ""
1789 LPRINT USING"TOTAL ACRES ASSIGNED = ............................... ###.#"
;ACRE
1790 LPRINT USING"TOTAL ACRES IRRIGATED = ............................. ###.#"
;AACRE
1795 LPRINT USING"LENGTH AND WIDTH OF FIELD = ....................... ##,###.#"
;X
1800 LPRINT USING "WATER HOLDING CAPACITY (in. of water per in. of soil) = #.###
";AMC(I)
1810 LPRINT USING "NUMBER OF DAYS SYSTEM WILL OPERATE DURING THE YEAR =... ###.#
";NOD
1820 LPRINT USING "SOIL UPTAKE RATE (INCHES PER HOUR)   = ............... #.###
";IPH(I)
1830 LPRINT USING "VERTICAL DISTANCE IN FEET = ......................... ###.#
";VD
1840 LPRINT USING "HORIZONTAL DISTANCE = ............................... ####.#
";HD
1850 LPRINT USING "PERCENT OF AVAILABLE WATER TO TRIGGER IRRIGATION = ... ##.###
```

```
%";TP*100
1860 LPRINT "SOIL TYPE = ..........................................";ST$(I)
1870 LPRINT USING "PLANT'S DAILY WATER REQUIREMENTS IN INCHES = ..... #.###
";CU
1880 LPRINT ""
1890 LPRINT USING "COST OF FUEL IN DOLLARS PER GALLON =..... $#.###
";CE
1900 LPRINT USING "COST OF OIL IN DOLLARS PER GALLON = ..... $#.###
";COIL
1910 LPRINT USING "HORSEPOWER COST ON A COST PER HORSEPOWER BASIS =..... $###.#
";CHP
1920 LPRINT USING "SELLING PRICE PER BUSHEL OF CORN = ..... $#.###
";CROPPC
1930 LPRINT USING "HOURLY WAGE RATE FOR LABOR = ..... $#.###
";WAGERT
1940 LPRINT USING "COST OF CAPITAL (INTEREST RATE) = .....  ##.##%
";IR*100
1950 LPRINT USING "YIELD PER ACRE WITHOUT IRRIGATION = ..... ###.#
";YPA(I)
1960 LPRINT USING "ADDITIONAL INPUTS WITH IRRIGATION (per acre) = ..... $##.##
";BI(I)
1961 LPRINT USING "PRICE OF BUYING AND BURYING MAIN PIPE (per foot) = ... $##.##
";CM
1962 LPRINT USING "PRICE OF SUBMAIN PIPE (per foot) = ..... $##.##"
;CS
1963 LPRINT USING "PRICE OF LATERAL PIPE (per foot) = ..... $##.##"
;CLP
1964 LPRINT USING "PRICE OF T-VALVE TO CONNECT LATERAL TO SUBMAIN = .... $###.##
";CTV
1970 LPRINT"**************************************************************************
****"
1980 LPRINT "    SECTION 2: PARAMETERS IMPACTING DESIGN OF THE SYSTEM"
1990 LPRINT"**************************************************************************
****"
2000 LPRINT""
2010 LPRINT USING "CYCLES PER SEASON = ..................................... #
#.##";NOD/DPI
2011 LPRINT USING "NUMBER OF DAYS PER IRRIGATION CYCLE =..................... #
#.##";DPI
2020 LPRINT USING "WATER APPLIED PER IRRIGATION CYCLE (in inches) = ..........
#.##";WAI
2030 LPRINT USING "NUMBER OF SETTINGS PER DAY = ............................ ##
#.##";NOSPD
2040 LPRINT USING "NUMBER OF GUNS PER SETTING = ............................ ##
#.##";GUN
2050 LPRINT USING "LENGTH OF ONE IRRIGATION RUN = ......................... ####
#.##";LL1
2060 LPRINT USING "LENGTH OF LATERAL IN ONE SETTING = ..................... ####
#.##";LL1A
2070 LPRINT USING "NUMBER OF LATERALS PER SETTING = ....................... ####
#.##";NOL
2072 LPRINT USING "NUMBER OF SETTINGS PER IRRIGATION CYCLE = ............. #####
.##";NOSPD*DPI
2074 LPRINT USING "ACRES PER SETTING = ..................................... #####
.##";APG*GUN
2075 LPRINT USING "TIME SYSTEM OPERATES DURING ONE SETTING (in hours) = ... ####
#.##";OHPS
2080 LPRINT USING "TIME TO MOVE SYSTEM BETWEEN SETTINGS (in hours) = ..... #####
.##";LABHR/4
2090 LPRINT USING "TIME PER IRRIGATION CYCLE ( in hours ) = ............... ####
```

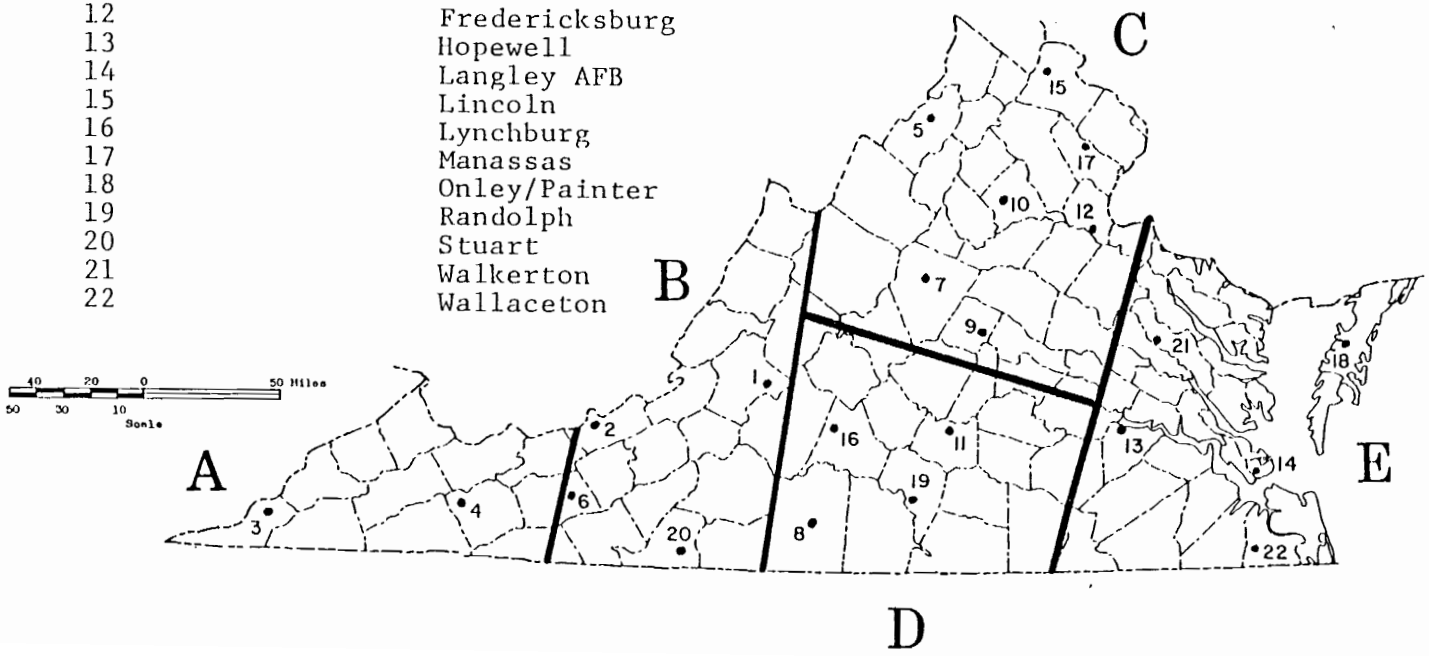
```
#.##";HPI
2100 LPRINT USING "TIME NEEDED TO OPERATE AND MOVE SYSTEM EACH DAY (in hours) =
##.#";THRPD
2110 LPRINT USING "LENGTH OF LATERAL PIPE = ..... #,#
##.#";TLL
2112 LPRINT USING "LENGTH OF SUBMAIN PIPE = ..... #,#
##.#";LSP
2116 LPRINT USING "LENGTH OF MAIN PIPE = ..... #,#
##.#";LSP
2120 LPRINT USING "ACRE-INCHES OF WATER BEING APPLIED = ..... #
##.#";AIPH
2122 LPRINT USING "GALLONS PER MINUTE IN ONE LATERAL = ..... #,#
##.#";GPM/NOL
2124 LPRINT USING "GALLONS PER MINUTE PER SPRINKLER..... #,##
#.#";GPM/GUN
2130 LPRINT USING "GALLONS PER MINUTE = ..... #,#
##.#";GPM
2140 LPRINT USING "TOTAL FRICTION LOSS IN SYSTEM = ..... #,#
##.#";TFL
2150 LPRINT USING "TOTAL HEAD OF SYSTEM = ..... #,#
##.#";TH
2160 LPRINT USING "DIAMETER OF LATERAL PIPE = .....
##.#";D
2165 LPRINT USING "DIAMETER OF SUBMAIN PIPE = .....
##.#";DS
2170 LPRINT USING "DIAMETER OF MAIN PIPE = .....
##.#";SD1
2180 LPRINT USING "VELOCITY OF WATER IN LATERALS ( in feet per second ) = .....
##.#";V1
2185 LPRINT USING "VELOCITY OF WATER IN SUBMAIN PIPE ( in feet per second ) =
##.#";V2
2190 LPRINT USING "VELOCITY OF WATER IN MAIN PIPE ( in feet per second ) = ...
##.#";V3
2200 LPRINT USING "FRICTION LOSS IN LATERALS ( per foot ) = ..... #.###
####";HFL
2205 LPRINT USING "FRICTION LOSS IN SUBMAIN ( per foot ) = ..... #.###
####";HFS
2210 LPRINT USING "FRICTION LOSS IN MAIN PIPE ( per foot ) =..... #.###
####";HFM
2220 LPRINT USING "HORSEPOWER OF SYSTEM = ..... ##
#.##";HP%
2225 LPRINT USING "BRAKE-HORSEPOWER HOURS PER SEASON = ..... ###,##
#.##";HPHR
2230 LPRINT "":REM CHR$(12);"":REM PAGE EJECT COMMAND
2240 LPRINT"*************************************************************************
2250 LPRINT"         SECTION 3: ANNUAL VARIABLE COST OF SYSTEM"
2260 LPRINT"*************************************************************************
2270 LPRINT"                                "
2280 LPRINT"                ON A PER ACRE BASIS"
2290 LPRINT"                ---------------------"
2300 LPRINT USING "ANNUAL VARIABLE COST = ..... $###,##
#.##";AVCPA
2309 LPRINT USING "ANNUAL LABOR COST INCLUDING TRANSPORTATION = ..... $###,##
#.##";LABHRS*WAGERT*NOD/AACRE
2310 LPRINT USING "ANNUAL LABOR COST = ..... $###,##
#.##";LABCOS/AACRE
2311 LPRINT USING "NUMBER OF LABOR HOURS NEEDED PER SEASON = .....  ###,##
#.##";LABHR*NOD/AACRE
2320 LPRINT USING "ANNUAL MAINTENANCE COST = ..... $###,##
#.##";MAINT/AACRE
```

```
2330 LPRINT USING "ANNUAL FUEL COST = ..................................... $###,
#.##";GALD/AACRE
2340 LPRINT USING "ANNUAL OIL COST = ..................................... $###,
#.##";GALO/AACRE
2350 LPRINT USING "ANNUAL COST FROM LOST PRODUCTION = ..................... $###,
#.##";COLP/AACRE
2360 LPRINT USING "ANNUAL COST FROM NEED FOR ADDITIONAL INPUTS =........ $###,
#.##";BI(I)
2370 LPRINT ""
2380 LPRINT"*************************************************************************
2390 LPRINT"        SECTION 4: ANNUAL FIXED COST FOR SYSTEM"
2400 LPRINT"*************************************************************************
2410 LPRINT""
2420 LPRINT"                    _____________________"
2430 LPRINT"                     ON A PER ACRE BASIS"
2440 LPRINT"                    ---------------------"
2449 LPRINT USING "TOTAL ANNUAL FIXED COST = ............................ $###,
#.##";AFCPA
2450 LPRINT USING "CAPITAL RECOVERY FACTOR = ............................ #.##
####";CRF
2460 LPRINT USING "ANNUALIZED INVESTMENT COST = ......................... $###,
#.##";(INVES*CRF)/AACRE
2470 LPRINT USING "TOTAL INVESTMENT COST = .............................. $###,
#.##";INVES/AACRE
2480 LPRINT USING "COST OF PUMP = ....................................... $###,
#.##";PUMPC/AACRE
2490 LPRINT USING "COST OF BUYING AND BURYING MAIN PIPE = ............... $###,
#.##";CMP/AACRE
2500 LPRINT USING "COST OF SUBMAIN PIPE = ............................... $###,
#.##";CSP/AACRE
2505 LPRINT USING "COST OF LATERAL PIPE = ............................... $###,
#.##";CL/AACRE
2507 LPRINT USING "COST OF T-VALVES = ................................... $###,
#.##";TVC/AACRE
2508 LPRINT USING "COST OF RISERS AND SPRINKLERS = ...................... $###,
#.##";TRG/AACRE
2510 LPRINT USING "TOTAL COST OF INSURANCE AND TAXES = ................... $###,
#.##";IRS/AACRE
```

APPENDIX B

This appendix contains a map of Virginia. This map outlines the five regions as defined by Van Bavel in **Agricultural Drought in Virginia** and used in this thesis.

Map Code Number	Station Name
1	Buchanan
2	Glen Lyn
3	Pennington Gap
4	Saltville/Marion
5	Woodstock
6	Wytheville
7	Charlottesville
8	Chatham
9	Columbia
10	Culpeper
11	Farmville
12	Fredericksburg
13	Hopewell
14	Langley AFB
15	Lincoln
16	Lynchburg
17	Manassas
18	Onley/Painter
19	Randolph
20	Stuart
21	Walkerton
22	Wallaceton

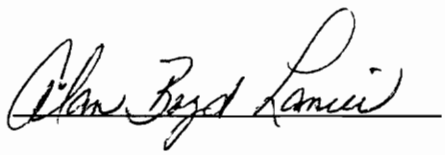


VITA

The author, son of Robert C. Lanier and Evelyn B. Lanier, was born in Richmond, Virginia in 1958. His first 18 years were spent living, working, learning, and having fun on a farm in Amelia, Virginia. In 1976, he graduated from Amelia County High School as the valedictorian of his class and entered Virginia Tech that Fall as an Agronomy major.

His undergraduate career was interrupted by a car accident in the Summer of 1978 that took a year from his life. Upon his return, he decided to enter the Agricultural Economics program. In 1981, he graduated from Virginia Tech with a Bachelor of Science degree with a double major in Agricultural Economics and Agronomy.

After a short period of teaching history to high school students, he entered Virginia Tech as a graduate student pursuing a Master of Science Degree in Agricultural Economics in 1982. After working at Sperry-New Holland as an Economist for two years, American Cyanamid as Market Research Analyst for two years, and Smithkline Beecham as Manager, Marketing Research and Forecast for four years, he was able to use 5 vacation days, return to Virginia Tech, and complete his thesis.



Alan Boyd Lanier

Irrigation Cost Models to Assess the Feasibility and Potential Expansion of Large-Scale Riparian Irrigation in Virginia

by

Alan Boyd Lanier

(ABSTRACT)

Three microcomputer based irrigation design programs were built using the BASIC language. The design models used agronomic, meteorological, economic, and environmental variables to design an irrigation system. Next, the design models computed the variable and fixed cost associated with a portable pipe, fixed big gun, traveling gun, and center pivot irrigation systems.

The more economically important variables impacting fixed and variable irrigation costs were randomized in a uniform and independent distribution using the random number generator in the BASIC language. The design models were simulated using these uniform distributions to build a database representing 3000 observations for each irrigation system for a total of 12,000 observations. Each of these 12,000 observations encompassed the variable cost, fixed cost, parameters of the irrigation system, and the number of drought days the system would be operating.

This database was analyzed to determine the relationships between cost and each of the variables. This analysis showed that all variables were linearly related to cost, except for field size. Further analysis showed that field size could be linearly transformed by using its inverse.

The database and ordinary least squares were used to build econometric equations which summarized the design models' information. These econometric equations were used in an example to show how these models could be used in a benefit-cost analysis. Since the benefit-cost analysis was relatively simple, further refinement of the models to include income taxes, inflation, and risk assessment is recommended.