Sprinkler irrigation system design model and application
by Usaid Izzat Suliman ElHanbali

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Agricultural Engineering
Montana State University
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Abstract:
Two computer programs were developed to design sprinkler irrigation hand-move systems. They take soil, plant, and climatic data as input and then design the different components of the sprinkler system. The first program, PROGRAM-1, determines the sprinkler head specifications required which are flow and wetted diameter. The second program, PROGRAM-2, designs the lateral and the main line, finds the power requirements, and does an economic analysis. Several sprinkler and lateral spacing combinations can be tested and the one selected is that which gives the most economical solution. The criterion for that selection will be the total annual cost per acre. The two programs are applicable to the areas where sprinkler irrigation is introduced for the first time. The programs are applicable to a hand-move sprinkler system with single size pipe laterals that run parallel to the contour lines and a main line perpendicular to the laterals which runs either up hill or level.
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Date  May 25, 1977
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AND APPLICATION

by

USAID IZZAT ELHANBALI

A thesis submitted in partial fulfillment
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May, 1977
The author would like to express his sincere appreciation to Dr. T. L. Hanson for his counsel and guidance throughout the study, to Dr. C. M. Milne and Dr. R. L. Brustkern for taking the time to be on the examining committee and reviewing the thesis.

The author would like also to thank the Agricultural Engineering Department and its head Dr. W. E. Larsen for the support and encouragement throughout the study.

Thanks to the computer for her aid in solving the problem. Finally my sincerest gratitude to my wife, Hana, to my son, Fauwaz, for their patience and inspiration during this study, and to my sister, Fadwa, to whom I owe everything.
# TABLE OF CONTENTS

| LIST OF TABLES                  | vi  |
| LIST OF FIGURES                | vii |
| ABSTRACT                       | viii|

## CHAPTER

1. **INTRODUCTION** .................................................. 1
2. **REVIEW OF SELECTED LITERATURE** .................................. 5
3. **GENERAL PROCEDURE** ........................................ 10
4. **PROGRAM-1** .................................................. 13
   - **INPUT INFORMATION** ........................................ 13
   - **CALCULATING PROCEDURE** ................................ 14
   - **OUTPUT** .................................................. 16
5. **PROGRAM-2** .................................................. 17
   - **INPUT INFORMATION** ........................................ 17
   - **CALCULATING PROCEDURE** ................................ 19
   - **OUTPUT** .................................................. 38
6. **RESULTS AND DISCUSSION** ...................................... 40
   - **RESULTS OF PROGRAM-1** .................................. 40
   - **RESULTS OF PROGRAM-2** .................................. 42
   - **DISCUSSION** ............................................... 58
   - **APPLICATION** .............................................. 58
   - **SUGGESTIONS FOR FURTHER RESEARCH** ...................... 60
7. **SUMMARY** ..................................................... 61
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Adjustment of Soil Intake Rate for</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Effect of Land Slope</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Selection of Sprinkler Wetted Diameter</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>With Respect to Average Wind Speed</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Selected Spacing Combinations</td>
<td>42</td>
</tr>
<tr>
<td>4.</td>
<td>Design of Lateral (First Run)</td>
<td>44</td>
</tr>
<tr>
<td>5.</td>
<td>Design of Main Line (First Run)</td>
<td>45</td>
</tr>
<tr>
<td>6.</td>
<td>Power Requirements (First Run)</td>
<td>46</td>
</tr>
<tr>
<td>7.</td>
<td>Economic Analysis (First Run)</td>
<td>47</td>
</tr>
<tr>
<td>8.</td>
<td>Design of Main Line (Second Run)</td>
<td>50</td>
</tr>
<tr>
<td>9.</td>
<td>Power Requirements (Second Run)</td>
<td>51</td>
</tr>
<tr>
<td>10.</td>
<td>Economic Analysis (Second Run)</td>
<td>52</td>
</tr>
<tr>
<td>11.</td>
<td>Design of Main Line (Third Run)</td>
<td>54</td>
</tr>
<tr>
<td>12.</td>
<td>Power Requirements (Third Run)</td>
<td>55</td>
</tr>
<tr>
<td>13.</td>
<td>Economic Analysis (Third Run)</td>
<td>56</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Lateral Configurations</td>
<td>26</td>
</tr>
<tr>
<td>2.</td>
<td>Sprinkler Irrigation System Layout (Fail Ranch Quadrangle-Montana)</td>
<td>41</td>
</tr>
<tr>
<td>3.</td>
<td>Effect of Sprinkler and Lateral Spacings on the Total Annual Cost per Acre (First Run)</td>
<td>48</td>
</tr>
<tr>
<td>4.</td>
<td>Effect of Sprinkler and Lateral Spacings on the Total Annual Cost per Acre (Second Run)</td>
<td>53</td>
</tr>
<tr>
<td>5.</td>
<td>Effect of Sprinkler and Lateral Spacings on the Total Cost per Acre (Third Run)</td>
<td>57</td>
</tr>
<tr>
<td>6.</td>
<td>Optimum Solution Analysis, Considering Main Line, Pumping, and Combined Annual Costs (30 x 50 ft spacing)</td>
<td>59</td>
</tr>
<tr>
<td>7.</td>
<td>Flow Chart of PROGRAM-1</td>
<td>69</td>
</tr>
<tr>
<td>8.</td>
<td>Flow Chart of PROGRAM-2</td>
<td>79</td>
</tr>
<tr>
<td>9.</td>
<td>Flow Chart of SUBROUTINE CLIMATE</td>
<td>80</td>
</tr>
</tbody>
</table>
Two computer programs were developed to design sprinkler irrigation hand-move systems. They take soil, plant, and climatic data as input and then design the different components of the sprinkler system. The first program, PROGRAM-1, determines the sprinkler head specifications required which are flow and wetted diameter. The second program, PROGRAM-2, designs the lateral and the main line, finds the power requirements, and does an economic analysis. Several sprinkler and lateral spacing combinations can be tested and the one selected is that which gives the most economical solution. The criterion for that selection will be the total annual cost per acre.

The two programs are applicable to the areas where sprinkler irrigation is introduced for the first time. The programs are applicable to a hand-move sprinkler system with single size pipe laterals that run parallel to the contour lines and a main line perpendicular to the laterals which runs either up hill or level.
Chapter 1

INTRODUCTION

"And with water we have made all which is living."
The Holy Koran

Irrigation has been practiced by man for thousands of years, and water had a crucial role in history, not merely as an adjunct of civilization, but as a stimulus to the development of civilization itself. It was no accident that the earliest civilizations arose in arid and semiarid regions, almost simultaneously in several parts of the world. The practice of irrigation was an essential ingredient of those civilizations.

The opinions among archeologists differ on the question whether flood irrigation was first developed in Mesopotamia or in the Nile Valley. The weight of evidence seems to favour Mesopotamia, where flood irrigation was practiced by about 6000 B.C. In the Nile Valley around 4000 B.C., cities became surrounded by flood irrigated fields which were controlled by gates. Basin-type irrigation began a little earlier than 3000 B.C., but by then irrigation was practiced in other parts of the world (Nace, 1975). Ancient irrigation works can be found in Egypt, Iran, Turkey, China, India, Iraq, Spain, England, and the Jordan Valley. In the western hemisphere, the inhabitants of Peru, Mexico, and the southwestern United States practiced irrigation thousands of years ago (Pair, 1975).
It was in early 1900's that pressure water systems of the cities were used to sprinkle lawns. After World War II, quick connecting lightweight steel and aluminum pipe, together with the impact-type sprinkler, made sprinkler irrigation feasible on almost all crops in both arid and humid areas of the world (Pair, 1975).

Sprinkler irrigation provides the essential soil moisture control needed for optimum crop yields. But, unless sprinkler irrigation is accompanied with good soil management, proper fertilization, insect and plant disease control, improved seed strains, and mechanized farming operations, these optimum crop yields cannot be achieved. Moreover, sprinkler irrigation, with its flexibility and efficient control of water application, permits a wide range of soil to be irrigated and has caused changes in land use classification that allows a much greater acreage to be classified as irrigable. Many improvements have been made in sprinkler irrigation equipment and today more information is available on proper operation, sprinkler spacings, pressures, nozzle sizes, weather conditions and system design.

The ultimate goal of a sprinkler-irrigation system design is to obtain a system with optimum nozzle capacity, sprinkler head spacing, lateral spacing, lateral size, main pipe size, and power requirements such that the irrigation system, in addition to meeting
the crop and soil requirements, is the most economical one. It is evident that there is a need for a computer program to aid in finding that most economical system. By using a computer, different system parameters can be analyzed rapidly and the optimum solution can be established.

Electronic computers with high speeds, large memory capacities and sophisticated monitor systems have been used extensively in engineering design. This study makes use of the computer in the field of irrigation design. One of the characteristics of the computer that makes it unique among technical achievements is that it has forced men to think about what they are doing with clarity and precision.

Though the computer program developed in this study is in general form, it is oriented to be used in the design of sprinkler systems for the newly irrigated areas in the Jordan Valley, Jordan. The hand-move sprinkler systems have been recommended for those areas in a previous feasibility study (Nedeco, 1974). Based on the annual cost analysis the study showed that sprinkler irrigation is more economical than surface irrigation, especially since labor cost has risen sharply in recent years. However, the developed computer program takes into consideration that research studies to determine crop consumptive use and the distribution patterns of
sprinklers with respect to local wind conditions are not available for these areas.

It is hoped that using a computer in sprinkler design and operation will make the design of sprinkler system components more efficient and the operation more precise, resulting in a more profitable irrigation system.
A review of the literature indicates that there have been no published studies which have the same objectives as this study. However, several studies have been similar in that they involve computer modeling to design solid set sprinkler irrigation systems, to determine the agriculture crop water requirements or to determine irrigation scheduling.

An early study made by Bruhn (1938) proposed a method for designing sprinkler irrigation systems based on cost analysis which included the initial cost but excluded water cost. Schenzer (1938) used 50 feet as lateral spacing in a similar sprinkler irrigation study.

The total equipment costs of sprinkler irrigation were studied again in the late forties by Peikert (1947) and Lewis (1949). They found an average cost of $75 per acre for light-weight portable pipe and a semi-portable system. The design of these systems was usually supplied by dealers. In the fifties, Jacobson (1952) found the average initial cost of sprinkler irrigation was about $4.00 per acre-in. Howland (1957) developed methods of selecting economical irrigation pipe by evaluating energy loss in the pipe and the cost of installation. The cost of water as a function of system-design variables was not included in their studies.
The use of uniformity of water distribution as criterion for evaluating efficiency of water application was studied by McCulloch (1949). His study indicated that for a good design, the type of sprinkler nozzle, its operating pressure, and main-line and lateral spacings, should be so selected as to limit variation in moisture distribution to 20 percent or less (uniformity 80 percent or more). The ASAE recommendations (1954) suggested that a sprinkler irrigation system should be designed to achieve a good uniformity of water application by selecting proper spacing, etc. It also recommended that the desirable operating pressures, spacing of sprinklers and nozzle size should be obtained from the sprinkler manufacturer. Various ways of describing uniformity were derived. The statistical parameters of collected sprinkler readings such as mean value, mean deviations and standard deviation are the ones commonly used. The most common and frequently used equations were those derived by Christiansen (1941), Wilcox (1955), Hart and Reynolds (1965). The use of computers in the sprinkler irrigation studies started in the early 60's. Hart (1963) used a digital computer to analyze the sprinkler distribution pattern. The program accepts observations from a single sprinkler and overlaps them to generate a rectangular pattern for the spacing desired. The generated patterns are then statistically analyzed for distribution characteristics by two procedures using uniformity coefficient principle.
Work on determining economical sprinkler spacings and lateral spacings are scarce in reference literature. Several studies looked at various components of a sprinkler irrigation system. Labor cost analysis was studied by Shull (1966). Korven (1965) studied initial equipment and labor cost. Keller (1965) investigated the most economical pipe-size combination which gives the minimum total fixed operation cost. ASAE recommendation (ASAE S262[T], Sprinkler Irrigation Technical Sheet) suggested a procedure for doing an economic analysis of sprinkler irrigation systems. The objectives of past sprinkler irrigation studies were either to develop methods to describe uniformity or to analyze equipment cost, both of which are used separately as criterion in evaluating and selecting sprinkler systems. But in a study by T. Liang and Wu, I-pai (1970), a computer program was developed to aid in the design of solid set sprinkler irrigation systems. In that study the criterion for a system design is the cost of the entire irrigation system (including equipment as well as water but excluding the pump), subject to crop, soil, and other restraints on the system. Also in that study it is necessary to test the sprinkler under field and wind conditions and the resulting precipitation data will be used in the program to evaluate the entire sprinkler system. The size of lateral and main line was determined by using the "slide rule" from the "Rain Bird Company," and by restraining the pressure loss to less than
10 percent of the operating pressure. The selection of an irrigation system criterion is the overall cost, in dollars per acre-inch, for delivering useful water to the root zone.

It is understood that some irrigation companies have developed their own programs to aid them in the design of sprinkler systems. These programs are not published nor available to the public. On the other hand, several studies have been made to determine the evapotranspiration and the consumptive use of crops, but these studies were primarily to schedule irrigation and not for determining the peak consumptive use as a basis for the design of irrigation systems. A computer program for the extensive computations that are required to evaluate the various estimating methods of evapotranspiration was prepared by R. D. Burman (Jensen, 1973). In a study by Nimer and Bubenzer (1972), a computer model was developed to determine the irrigation potential of selected land areas. A data bank containing crop, soil, and probable well yield data was developed for the state of Wisconsin. This data plus information furnished by the prospective irrigator is used to evaluate the potential irrigation of the selected area.

USDA has developed a computer program for irrigation scheduling (Jensen, 1972). The computer program requires limited input data and uses simple, basic equations so that each can be replaced as more accurate relationships are developed. The U. S.
Bureau of Reclamation has modified the program to provide general irrigation forecasts for the major crops in an area.
Chapter 3

GENERAL PROCEDURE

In the design of sprinkler irrigation systems, the selection of a sprinkler and lateral spacing combination is one of the most difficult parts of the design. Usually the selection of the spacing combination is based on judgment and/or local experience. Thus, this selection does not take into consideration the effect of spacing combination on the overall cost of the sprinkler system and on the total annual cost per acre for that system. Moreover, for a newly irrigated area without background or experience in sprinkler irrigation, the selection of a specific spacing combination will be only a matter of judgment which may not give the most efficient design and the least cost system.

The two computer programs developed in this study, PROGRAM-1 and PROGRAM-2 are to design a hand-move sprinkler irrigation system with laterals running parallel to the contour lines and the main line running perpendicular to the laterals, uphill or level. Different spacings of sprinklers on the lateral and of the laterals on the main line are tested and the optimum solution can be then established.

PROGRAM-1 is to determine the sprinkler head specifications in order to select the appropriate sprinkler heads. In the procedure described afterwards, the adjustment of the soil intake rate and the
calculation of the wetted diameter are based on the material in "Sprinkler Irrigation Handbook" by Fry and Gray (1971). PROGRAM-1 has one subroutine, SOIL SUBROUTINE, in which soil information is read and it will also be used in PROGRAM-2. This subroutine will be useful to read the soil data if there is more than one type of soil, or if coding of the different types of soil is desired. An illustrative flow chart for PROGRAM-1 is presented in Appendix A Figure 7, a variable glossary in Appendix B, a listing of the program in Appendix C, and an example output of the program in Appendix D.

PROGRAM-2 is to calculate crop peak daily use, irrigation interval, lateral operating hours, number of lateral sets per day and number of laterals. It is also to size the laterals, the main line and the valves. Then power requirements and economics are analyzed. Sizing of laterals and main line, calculating the power requirements and doing the economic analysis are processed as described in "Sprinkler Irrigation" by C. H. Pair (1975). PROGRAM-2 has five subroutines: SOIL SUBROUTINE to input soil data, PLANT SUBROUTINE to input plant data, CLIMATE SUBROUTINE to input climatic data and to calculate the crop peak daily consumptive use as described in Jensen-Haise method (1963, 1966), SPRINKLER SUBROUTINE to input the selected sprinkler head specifications, and INPUT SUBROUTINE to write the input data needed to run this program. By
using subroutines it is possible to reduce the total program size and the amount of branching which must be done in the program. It is usually simpler for a programmer to handle subroutines which are separated physically, rather than attempting to integrate them in the program by branching. Illustrative flow charts for PROGRAM-2 and SUBROUTINE CLIMATE are presented in Appendix E, Figure 8, and Figure 9 respectively. A variable glossary is provided in Appendix F, a listing of the program in Appendix G, and an example output of the program in Appendix H.

The language used in these two programs is FORTRAN IV, and the computer machine is Xerox Sigma 7. The computer time needed to run PROGRAM-1 is 1 minute, and PROGRAM-2 is 2 minutes.
Chapter 4

PROGRAM-1

PROGRAM-1 is a computer program to determine sprinkler head specifications taking into account the intake rate of the soil and the average speed of prevailing winds.

INPUT INFORMATION

Since the application rate of a sprinkler should be equal or slightly less than the intake rate of soil, to insure no runoff, the intake rate of the soil should be determined. This intake rate should then be adjusted for slope effect (Pair, 1975). Also in selecting the soil intake rate values for sprinkler system design, it is essential not to use initial rates, but to select a rate which will prevail during the total irrigation (Pair, 1975). The soil input information, in addition to the intake rate in inches per hour, will include: type, texture, depth in feet, and holding capacity of that soil in inches per foot. This information will be read in SUBROUTINE SOIL, and will be used later in PROGRAM-2.

The other input information needed to run this program is the average speed of prevailing winds in MPH during the growing season. Based on this information and on Irrigation Guides or local experience, different spacings between sprinklers on the
laterals (SL) in feet, and spacings of laterals on main line (SM) in feet, are read into the program. If field observations for the distribution pattern of sprinklers are available, taking into consideration the wind velocity, wind direction, and risers height, the spacings selected should be based on this information.

CALCULATING PROCEDURE

Once all of the above information is read into the program, the computer is ready to start calculating the sprinkler head flow in GPM and the wetted diameter in feet for the different spacings. First it will adjust the soil intake rate for slope effect as shown in Table 1.

Table 1
Adjustment of Soil Intake Rate for Effect of Land Slope

<table>
<thead>
<tr>
<th>Slope</th>
<th>Intake Rate Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0- 5% grade</td>
<td>0%</td>
</tr>
<tr>
<td>6- 8% grade</td>
<td>20%</td>
</tr>
<tr>
<td>9-12% grade</td>
<td>40%</td>
</tr>
<tr>
<td>13-20% grade</td>
<td>60%</td>
</tr>
<tr>
<td>over 20%</td>
<td>75%</td>
</tr>
</tbody>
</table>
Next it will read the average speed of prevailing winds (AWS) in MPH and the different spacings of sprinklers on laterals (SL) in feet and the different spacings of laterals on the main line (SM) in feet. Then it will calculate the flow of each sprinkler for each combination of (SL) and (SM), as follows:

\[ Q = \frac{\text{IRA} \times \text{SL} \times \text{SM}}{96.3} \]  \hspace{1cm} (1.1)

where

\[ Q \] = Flow of sprinkler in GPM  \\
\[ \text{IRA} \] = Adjusted intake rate of the soil in inches/hour  \\
\[ \text{SL} \] = Spacing of sprinklers on the lateral in feet  \\
\[ \text{SM} \] = Spacing of laterals on the main line in feet

Next it will calculate the wetted diameter of the sprinkler for each combination of (SL) and (SM) as shown in Table 2.

<table>
<thead>
<tr>
<th>Average Wind Speed</th>
<th>Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 7 MPH</td>
<td>SL = 40% of wetted dia.</td>
</tr>
<tr>
<td></td>
<td>SM = 65% of wetted dia.</td>
</tr>
<tr>
<td>Up to 10 MPH</td>
<td>SL = 40% of wetted dia.</td>
</tr>
<tr>
<td></td>
<td>SM = 60% of wetted dia.</td>
</tr>
<tr>
<td>Above 10 MPH</td>
<td>SL = 30% of wetted dia.</td>
</tr>
<tr>
<td></td>
<td>SM = 50% of wetted dia.</td>
</tr>
</tbody>
</table>
OUTPUT

PROGRAM-1 will give the desired flow of the sprinkler in GPM and the wetted diameter of sprinkler in feet, for each combination of (SL) and (SM) spacings. This output will be used to select the available commercial sprinkler heads. The specifications of the selected sprinkler heads will be then read into PROGRAM-2.
Chapter 5

PROGRAM-2

PROGRAM-2 is a computer program to design laterals, main lines, size valves, find power requirements and do an economic analysis. It consists of MAIN PROGRAM-2 and five subroutines, namely SUBROUTINE SOIL, SUBROUTINE PLANT, SUBROUTINE CLIMATE, SUBROUTINE SPRINKLER and SUBROUTINE INPUT.

Before running this program it is assumed that the engineer has determined the layout of the sprinkler system. Thus there will be a good estimate of the length of both the lateral and the main line, and the difference in elevation between the pump and the end lateral. This program is written for systems with the laterals running parallel to the contour lines and the main line perpendicular to the laterals either up hill or level.

INPUT INFORMATION

PROGRAM-2 takes soil, plant and climatic data as input. It also takes as input the specifications of the selected sprinkler heads, as determined by PROGRAM-1 output.

The soil data includes type, texture, holding capacity in inches per foot, depth in feet, intake rate in inches per hour and slope as a percentage. This information will be read into the SUBROUTINE SOIL. The plant data includes name of crop and its root
zone depth in feet. This information will be read into the SUBROUTINE PLANT. The climatic data includes maximum and minimum daily temperatures in °F, daily solar radiation in cal cm⁻² or langley, and effective daily precipitation in inches. Since this data will be used in calculating the peak daily consumptive use, which occurs about July 15 to July 25 in the northern hemisphere (Jensen, 1972), the data read in this program will be the average daily data of July. This information will be read into the SUBROUTINE CLIMATE. The other information that is read into this subroutine is the average elevation of irrigated area (E) in feet, crop factor (KC) and Jensen-Haise constant C2.

The sprinkler head specifications will be read into the SUBROUTINE SPRINKLER. The selection of these specifications will be according to the output of PROGRAM-1. These specifications include type, flow in GPM, wetted diameter in feet, pressure in psi and nozzle diameter in inches. Also the different spacings of sprinklers on the laterals (SL) in feet, and those of laterals on the main line (SM) in feet and the cost of sprinkler heads in dollars, will be read into the same subroutine.

The other information needed to run this program will be read into the MAIN PROGRAM-2 and will include:

Leaching requirements in inches

Efficiency of sprinkler system in decimal form
Area to be irrigated in square feet
Length of lateral in feet
Length of main line in feet
Hazen-Williams coefficient (C)
Exponent (M) in Hazen-Williams equation for head loss in pipes
Elevation at the center line of the pump in feet
Suction head on the pump in feet (assuming centrifugal pump)
Pump efficiency in decimal form
Net seasonal irrigation requirements in inches
Cost per kwh in dollars
Demand cost in dollars
Efficiency of the motor in decimal form

Note that the cost of the different diameters of aluminum and steel pipes and the cost of main line risers used in the main program should be changed to meet local current prices.

CALCULATING PROCEDURE

PROGRAM-2 consists of MAIN PROGRAM-2 and of five subroutines. The calculating procedure of the MAIN PROGRAM-2 and the subroutines are as follows.
MAIN PROGRAM-2

After reading the input information, the calculating procedure will be:

1. Calling the SUBROUTINES: SOIL, PLANT, CLIMATE, SPRINKLER, and INPUT.

2. Calculate the peak daily use of crop:
   
   Peak Daily Use = Average Peak + Leaching Requirements (1.5)

   where the average peak of the crop daily consumptive use has been calculated in SUBROUTINE CLIMATE.

3. Calculate net and gross moisture to be replaced each irrigation. This is based on root zone depth of crop and soil depth. If soil depth is less than root zone depth, the root zone depth is limited to the value of soil depth. The available moisture content of the soil is equal to:

   \[ \text{AMC} = \left( \frac{\text{Holding Capacity/ft}}{\text{ft}} \right) \times \text{Root Zone Depth} \quad (2.5) \]

   The allowable percentage of soil moisture depletion before irrigating is a function of crop, its root zone depth, soil type and texture, irrigation policy and economics. However, in this program, the criterion for determining this percentage and calculating the net moisture to be replaced each irrigation is arbitrary and based on the following assumptions:

   High value shallow rooted crops (RZ ≤ 3 ft) maintain 67% available moisture
For lower value deeper rooted crops (RZ≤5ft) maintain 50% available moisture.

For low value deep rooted crops (RZ>5ft) maintain 33% available moisture.

These assumptions can be altered depending on the availability of local data and on the engineer's experience, i.e., in a study on when to irrigate alfalfa (Hanson, 1972), little difference in yield or the amount of water used per unit of hay produced was found when irrigations were made within the range of 20 to 75 percent of the available soil moisture remaining.

The gross moisture to be replaced each irrigation is equal to:

\[ GMR = \frac{\text{Net Moisture Replaced}}{\text{Efficiency of Sprinkler System}} \]  

(3.5)

4. Calculate irrigation interval, irrigation period, lateral operating hours, number of sets per lateral per day, and number of laterals:

\[ \text{Irrigation Interval} = \frac{\text{Net Moisture Replaced}}{\text{Peak Daily Use}} \]  

(4.5)

The irrigation interval should be usually an integer number. This program allows 0.10 day as a maximum before truncating the value of the irrigation interval calculated by equation (4.5).
Lateral Operating Hours = \( \frac{\text{Gross Moisture Replaced}}{\text{Application Rate}} \) \hspace{1cm} (5.5)

where the application rate is calculated in the SUBROUTINE SPRINKLER.

Since the sprinkler system designed by this program is a hand-move semi-portable system, one hour is allowed to move the lateral. So for lateral operating hours less or equal 7, three sets per lateral per day are possible. If lateral operating hours is greater than 7 and less than or equal to 11, two sets are possible; otherwise only one set is possible.

Number of laterals =

\[
\text{Area to be Irrigated (sq. ft)} \div \text{No. of sets/day} \times \text{SM (ft)} \times \text{Irrigation Interval (days)} \times \text{length of lateral (ft)} \hspace{1cm} (6.5)
\]

Irrigation Period =

\[
\frac{\text{length on the Main Line Irrigated by One Lateral}}{\text{SM} \times \text{No. of Sets/lateral/day}} \hspace{1cm} (7.5)
\]

where the Length on the Main Line Irrigated by One Lateral =

\[
\frac{\text{Area to be Irrigated (sq. ft)}}{\text{Lateral Length (ft)} \times \text{No. of Laterals}} \hspace{1cm} (8.5)
\]

and \( \text{SM} \) = Spacing of laterals on the main line in feet

5. Design of Lateral: this program is limited to a single size pipe lateral. In order to obtain the high water application efficiencies possible with sprinkler irrigation, it is essential to keep the variation in pressure at a practical minimum. For good
design, the variation should be held to ±10 percent of average lateral design pressure (ASAE minimum performance for sprinkler systems). On level ground, the case assumed here, this would mean holding the pressure drop due to friction to 20 percent between the first and the distal sprinkler. For practical purposes, allowable friction loss can be computed by multiplying the required average pressure (determined by the sprinkler selected) by 23.4 percent (Pair, 1975).

To simplify the computations of the losses in the laterals, they are assumed mainly as the friction losses in the pipe. Christiansen's procedure (1942) for calculating losses in pipes with multiple outlets is used here:

$$H_f = F \left( \frac{K L Q^{m/n}}{D^{2m+n}} \right) \quad (9.5)$$

in which

- $H_f$ = head loss in feet
- $k$ = a friction factor based on the friction formula used (here it is Hazen-Williams Eq.)
- $L$ = the length of pipe line in feet
- $Q$ = the total flow into the lateral in cu.ft./sec
- $D$ = the diameter of pipe in ft
- $F$ = is a factor for multiple outlets effect on friction losses
The exponent \( m \), velocity exponent, and \( n \), a pipe diameter exponent, are based on the formula used.

The diameter of pipe computed by equation (9.5) is to be rounded to the nearest commercial diameter. This program allows only 0.10 inches as a maximum increase in the pipe diameter before it is rounded to the next diameter.

6. Design of Main Pipe Line: there are a number of varying conditions which may govern the design of main lines (Pair, 1975). The selection of the economical pipe sizes is an engineering consideration of as much importance as the solution of the hydraulic problems involved (Keller, 1965). However, in this program the trial-and-error method is used. By running the program several times, the most economical solution for the whole sprinkler system can be established.

In the first run of this program, the loss of 1 ft head per 100 ft of the pipe length is used as a "rule of thumb" to determine the diameters of the several parts of the main line. In the subsequent runs, these diameters may be increased or decreased to obtain the most economical solution for the whole sprinkler system. The criterion for that is the total annual cost per acre. However, it is also necessary to examine the velocity of flow before increasing or decreasing the diameters of the main line segments.
and to keep these values within the allowable limits for each pipe material.

Hazen-Williams equation for head loss in pipes is used to calculate the pipe diameter:

\[
D = \left( \frac{10.43 \times L^{1.85}}{C^{1.85} H_{1}} \right)^{1/4.87}
\]

(10.5)

in which

- \(D\) = pipe diameter in inches
- \(L\) = length of pipe in feet
- \(Q\) = flow of the pipe in gallon per minute
- \(C\) = Hazen-Williams coefficient
- \(H_{1}\) = head loss in feet

PROGRAM-2 can handle the configurations of laterals on the main line shown in Fig. 1, i.e., from two laterals on the main line up to twelve laterals. For more than twelve laterals, the program can be easily modified. Also PROGRAM-2 is applicable to buried main lines which run uphill or on level ground. For downhill main lines, special consideration must be given to the elevation difference if the average slope gradient exceeds the friction-head gradient.

7. Calculate Power Requirements: the total dynamic head on the pump may be determined by the following equation:
Figure 1. Laterals Configurations
(Continue) Figure 1. Laterals Configurations
\[ H = 2.31P + \Delta E + \Sigma H_{\ell} + \Sigma H_{\ell m} + H_S \]  

(11.5)

in which

- \( H \) = total dynamic head on the pump in feet
- \( P \) = lateral inlet pressure in psi
- \( \Delta E \) = difference in elevation between the pump and end lateral in feet
- \( \Sigma H_{\ell} \) = sum of main line friction losses in feet
- \( \Sigma H_{\ell m} \) = sum of minor losses in feet
- \( H_S \) = suction head on the pump in feet (assuming centrifugal pump)

In this program, the minor losses are accounted for by increasing the value of the suction head by a reasonable amount.

Water horsepower can be calculated by:

\[ WHP = \frac{QH}{3960} \]  

(12.5)

where

- \( WHP \) = water horsepower
- \( Q \) = total flow in gallon per minute
- \( H \) = total dynamic head on the pump in feet

The brake horsepower can be calculated by:

\[ BHP = \frac{WHP}{\text{Pump Efficiency}} \]  

(13.5)

The required electrical horsepower can be determined by:

\[ EHP = \frac{BHP}{\text{Efficiency of Motor}} \]  

(14.5)
8. Sizing of Different Valves: for sizing the flow control and check valves, their diameters should equal the diameter of the main line next to the pump. For sizing the air release and vacuum relief valve, the ASAE recommendations are:

<table>
<thead>
<tr>
<th>Pipe Dia.</th>
<th>Valve Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>6&quot;</td>
<td>2&quot;</td>
</tr>
<tr>
<td>7-10&quot;</td>
<td>3&quot;</td>
</tr>
<tr>
<td>12&quot;</td>
<td>4&quot;</td>
</tr>
</tbody>
</table>

The SCS recommendations are:

<table>
<thead>
<tr>
<th>Pipe Dia.</th>
<th>Valve Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>4&quot; or less</td>
<td>(\frac{1}{2})&quot;</td>
</tr>
<tr>
<td>5-8&quot;</td>
<td>1&quot;</td>
</tr>
<tr>
<td>10-12&quot;</td>
<td>2&quot;</td>
</tr>
</tbody>
</table>

For sizing the pressure relief valves, see the ASAE recommendations for different pipe materials or any other tentative recommendations.

9. Economic Analysis: PROGRAM-2 will do an economic analysis for the whole sprinkler system as follows (prices and estimates obtained from Western Montana irrigation equipment dealer):

A. Equipment and Installation Costs which includes:
   1. water supply cost
   2. conveyance cost
   3. pump and power unit cost
4. distribution system cost: sprinkler heads, laterals, main line and riser costs. The costs of other components of the main pipe line such as valves, couplers, and plugs, elbows, etc., is assumed as 2 percent of the pipe cost.

5. installation cost: assumed as 10 cents/inch/feet length of the steel main pipe line. The installation cost of the pump and power unit is included in the purchase price.

B. Annual Fixed Costs: to compute the annual fixed costs, the average life of the sprinkler system has been assumed to be fifteen years. A compound interest rate of 9 percent has also been assumed, and the amortization factor (AF) for that has been obtained. This factor gives the annual charge for owning the facility on the basis of returns per year if the capital had been invested at a desired (9 percent) rate of interest (Pair, 1975).

C. Annual Operation and Maintenance Costs includes: the costs incurred for water, fuel, lubrication, electricity, labor, taxes, insurance, and repairs to the equipment. For calculating the power cost, the
In case of electrical power, there will be cost per H.P. demand or a "demand charge" in addition to the cost per kwh. So the annual power cost will be:

\[ \text{APC} = \text{CKWH} \times \text{SHOURS} \times \text{EHP} \times 0.746 + \text{CDEMAND} \times \text{EHP} \]  \hspace{1cm} (16.5)

where

\text{APC} = \text{annual power cost - dollars}

\text{CKWH} = \text{cost per kwh - dollars}

\text{SHOURS} = \text{operating hours during the season (calculated in eq. 15.5)}

\text{CDEMAND} = \text{cost per H.P. demand "demand charge" - dollar/EHP}

\text{EHP} = \text{electrical horsepower}

Note that the value of EHP should be adjusted to the available motor sizes.
Annual Maintenance Cost: for hand-move sprinkler systems, it is assumed as 2 percent of the initial cost of the equipment (Pair, 1975).

Annual Labor Cost: for hand-move sprinkler systems, the labor is from 0.7 to 1.0 hrs/acre/irrigation (Pair, 1975). In this program the labor cost is assumed to be $2.00/hour.

Taxes and Insurance: it is assumed as 2 percent of the initial cost of the equipment (Pair, 1975).

D. Total Annual Costs: equal the sum of the Annual Fixed Costs and the Annual Operation and Maintenance Costs. The Total Annual Cost per Acre is equal to the Total Annual Costs divided by the area to be irrigated in acres.

E. Annual Farming Cost per Acre: includes the cost of fertilizers, harvesting and related expenses.

F. Net Annual Income per Acre: equals the total annual income per acre minus the annual farming cost per acre.

G. Annual Profit or Loss per Acre: equals the Net Annual Income per Acre minus the Annual Cost per Acre. Negative sign means loss.
H. Years Needed to Pay for the System: equals the cost of the system per acre divided by the annual profit per acre, if any.

I. Annual Main Line Cost and Annual Pumping Cost: the annual main line cost is equal to the main line cost multiplied by the amortization factor (AF). The pumping annual cost is equal to the pump and power unit annual cost and the annual power cost.

After completing the economic analysis for the sprinkler system, the criterion of comparing the different systems will be based on the Annual Profit per Acre. The higher this value is, the more economical the system. However, a sensitive analysis of the program output is also essential to get a better idea of the economics of each system.

Subroutines

SUBROUTINE SOIL: in this subroutine, the soil input information is read. It includes type, texture, depth in feet, intake rate in inches per hour, the average slope as percentage, and the holding capacity of the soil in inches per foot.

SUBROUTINE PLANT: in this subroutine, the plant input information is read. It includes name of crop and its root zone depth in feet.
SUBROUTINE CLIMATE: this subroutine will calculate the crop peak daily consumptive use and the average peak, to be used as basis for designing the sprinkler system. The Jensen-Haise procedure for estimating crop consumptive use is selected because in this procedure, unlike most of the other available procedures, the crop coefficient need not be adjusted when transferring them from one location to another. This obviates the need for personal knowledge of the local area on the part of the user (and thus eliminates a possible source of bias in evapotranspiration determination). It should be noted here that the crop consumptive use is defined in this program, for the sake of computations, as the amount of evapotranspiration in inches minus the effective precipitation in inches.

The input data read into this subroutine includes:
1 - Long term averages for warmest month (July in the northern hemisphere):
   a - Mean maximum daily temperature in °F (TX)  
   b - Mean minimum daily temperature in °F (TN)  
2 - Mean daily solar radiation in cal cm⁻² or langleys (RS)  
3 - Effective mean precipitation in inches (PP)  
4 - Average elevation of the land in feet (E)  
5 - Jensen-Haise crop factor (KC)  
6 - Jensen-Haise constant (C2)
The calculating procedure of this subroutine is as follows:

1 - Basic Jensen-Haise Equation:

\[
ETP = CT \left( T - TO \right) RSS
\]  \hspace{1cm} (17.5)

where

- \( ETP \) = potential evapotranspiration - inches
- \( CT \) = temperature coefficient - \( (^{\circ}F)^{-1} \)
- \( T \) = mean daily temperature - \( ^{\circ}F \)
- \( TO \) = temperature intercept - \( ^{\circ}F \)
- \( RSS \) = total short wave solar radiation - inches of evaporation equivalent

\( CT \) can be calculated by the following equation:

\[
CT = 1.0/\left( C1 + C2 CH \right)
\]  \hspace{1cm} (18.5)

where

- \( C1 \) = 68 - 3.6 \( E /1000 \) for rough crops
- \( C1' \) = 81 - 4 \( E /1000 \) for grass
- \( C2 \) = 13 for rough crops and grass
- \( CH \) = \( 37.5 / (PSX - PSN) \)

\( PSX \) = saturated vapor pressure at \( TX \) (\( PSX \) in mm Hg)
\( PSN \) = saturated vapor pressure at \( TN \) (\( PSN \) in mm Hg)

\( PSX \) and \( PSN \) may be obtained from table of saturated vapor pressure of water versus temperature, or computed using the following equation:
\[
\frac{25.04 \, T - 5.162 \ln \left( \frac{T}{273} + 1 \right)}{T + 273}
\]

(19.5)

\[ PS = 4.58 \, e \]

where \( T \) is \( TX \) or \( TN \) in \( ^\circ C \).

\( TO \) may be calculated as follows:

\[ TO = 27.5 - 0.33 \left( PSX - PSN \right) - \frac{E}{1000} \]

(20.5)

this will give \( TO \) in \( ^\circ F \).

2 - Crop Daily Consumptive Use is computed as follows:

\[ ET = KC \times ETP \]

(21.5)

where

\( ET \) = crop evapotranspiration - inches

\( KC \) = is a dimensionless crop coefficient obtained from Jensen-Haise crop curves of \( KC \) versus stage of crop growth

\( ETP \) = potential evapotranspiration - inches

Then the crop consumptive use, as defined earlier, is equal to:

\[ CU = ET - PP \]

(22.5)

where

\( CU \) = crop consumptive use - inches

\( ET \) = crop evapotranspiration - inches

\( PP \) = effective mean precipitation - inches

However, it was found that the value of the crop consumptive use calculated by equation (21.5) is higher than most published data (Fry and Gray, 1973; Pair, 1975; FAO, 1975). This may be due
to the fact that the period of the climatic data used is not long enough to give a representative mean value. So an average value for crop consumptive use is computed by dividing the value of crop consumptive use, calculated by equation (22.5), by 7 (average irrigation interval). The principle of crop stress criterion may be used also to obtain a reasonable value of the crop consumptive use. The Food and Agriculture Organization of the United Nations (1975) suggested that the detailed design of the irrigation system be based on 5-10 days peak supply.

SUBROUTINE SPRINKLER: in this subroutine the specifications of the selected sprinkler heads, based on PROGRAM-1 output, are read. They include type, flow in GPM, wetted diameter in feet, pressure in psi, and the nozzle diameter of sprinkler in inches. The different spacings (SL) and (SM) in feet and the cost of sprinkler heads in dollars, will also be read in this subroutine. Once the above information is read into the subroutine, it will proceed to calculate the application rate of each sprinkler as follows:

\[
AR = \frac{96.3 \times Q}{(SL \times SM)}
\]  

(23.5)

where

\( AR \) = application rate of sprinkler - inches / hour
\( Q \) = flow of sprinkler - gallon per minutes
\( SL \) = spacing of sprinklers on the lateral - feet
SUBROUTINE INPUT INFORMATION: this subroutine will write
the input information read in the MAIN PROGRAM-2 and the other four
subroutines.

OUTPUT

PROGRAM-2 output gives the following:

1. Crop consumptive use, crop average consumptive use,
crop peak daily use, available moisture content, net moisture
replaced each irrigation, gross moisture replaced each irrigation,
and irrigation interval.

2. Design of lateral showing the required pipe diameter,
operating hours, number of lateral sets per day, number of laterals,
number of sprinklers, head loss, velocity of flow, irrigation period,
and sprinkler application rate.

3. Design of main line showing the diameters, head loss,
and velocity of flow in the main line segments. The design also
shows the total energy head at the end of each main line segment.

4. Size of the different valves.

5. Power requirements showing the head on the pump, total
flow, water horsepower, brake horsepower, and required electrical
horsepower.
6. Economic analysis showing initial cost of the different components of the system, annual cost, net annual income per acre, annual profit or loss per acre, number of years needed to pay for the system, annual main line cost, and annual pumping cost.
Chapter 6

RESULTS AND DISCUSSION

PROGRAM-1 and PROGRAM-2 were tested for an example area. The area lies in the N\textsuperscript{1/2}, Sec. 3, R30E T-N Fail Ranch Quadrangle-Montana. Fig. 2 shows the layout of the sprinkler system selected for this area. Ten different combinations of sprinkler spacings on the laterals (SL) and those of the laterals on the main line (SM) were used in running the two computer programs to find the optimum design for this area. A 60 foot spacing was the maximum spacing allowed for either the sprinklers or the laterals, based on the local practice in Montana. The ten spacing combinations are shown in Table 3, page 42.

The input information used to run the two programs and the results of running them will be discussed separately.

RESULTS OF PROGRAM-1

The input information used to run this program, in addition to the spacings presented in Table 3, and the results of the program are shown in Appendix D. The program determines the sprinkler head specifications required for each spacing combination. It calculates the sprinkler head flow in GPM and the wetted diameter in feet. The results of this program were used to select the sprinkler head specifications, which then were used as an input in PROGRAM-2.
Figure 2. Sprinkler Irrigation System Layout

(Fail Ranch Quadrangle - Montana)
Table 3
Selected Spacing Combinations

<table>
<thead>
<tr>
<th>No.</th>
<th>Spacing of Sprinklers on the Lateral (ft)</th>
<th>Spacing of Laterals on the Main Line (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
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</tr>
<tr>
<td>5</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
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<td>60</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
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<td>60</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

RESULTS OF PROGRAM-2

The input information used to run this program, as well as the results of running this program several times, are shown in Appendix H and in Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13. Running this program several times is intended to establish the
most economical solution for the whole sprinkler system. By changing the diameters of the main line segments and subsequently the power requirements, new cost for the sprinkler system is obtained. The criterion for establishing the most economical solution will be then the total annual cost per acre. However, as mentioned before, it is necessary to examine the velocity of flow in each segment of the main pipe line before changing the diameters of those segments. In this example run, the lower limit of the velocity of flow in the main line (steel pipe) was kept to about 2.5 fps to avoid sedimentation in the pipe, and the upper limit to about 9 fps to avoid damage to the pipe by water hammer or surge. A discussion of each of the runs follows.

First Run

In the first run of PROGRAM-2, the input information is the same as presented in Appendix H. The loss of 1 foot head per 100 feet of the main line length is used as a "rule of thumb" to determine the diameters of the main line segments. The results of this run are presented in Tables 4, 5, 6, and 7 which show the design of the lateral, the design of the main line, the power requirements, and the economic analysis of the whole system, respectively. Figure 3 shows the effect of sprinkler and lateral spacings on the total annual cost per acre in that case.
Table 4

Design of Lateral (First Run)

<table>
<thead>
<tr>
<th>SL (ft)</th>
<th>SM (ft)</th>
<th>Operating Hours</th>
<th>No. of Sets Per Day</th>
<th>No. of Laterals</th>
<th>No. of Sprinklers</th>
<th>Pipe Dia. (in.)</th>
<th>Head Loss (ft)</th>
<th>Velocity of Flow (fps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>30</td>
<td>5.13</td>
<td>3</td>
<td>12</td>
<td>44</td>
<td>4</td>
<td>24.32</td>
<td>6.35</td>
</tr>
<tr>
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<td>40</td>
<td>5.16</td>
<td>3</td>
<td>9</td>
<td>44</td>
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<td>29.73</td>
<td>5.38</td>
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<td>5.13</td>
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<td>7</td>
<td>44</td>
<td>5</td>
<td>24.32</td>
<td>6.77</td>
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<td>6</td>
<td>44</td>
<td>5</td>
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<td>7.87</td>
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<td>5.21</td>
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<td>9</td>
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<td>7</td>
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<td>6.84</td>
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<td>6</td>
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<td>5</td>
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<td>5.27</td>
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<td>6</td>
<td>22</td>
<td>5</td>
<td>32.43</td>
<td>7.91</td>
</tr>
<tr>
<td>SL (ft)</td>
<td>SM (ft)</td>
<td>Diameter of Main Line Segments (inches)</td>
<td>Vel. of Flow in the Main Line Segments (fps)</td>
<td></td>
<td></td>
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<td>--------</td>
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<tr>
<td></td>
<td></td>
<td>D1  D2  D3  D4  D5  D6</td>
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</table>
Table 6

Power Requirements (First Run)

<table>
<thead>
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<th>SL (ft)</th>
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Table 7
Economic Analysis (First Run)*
(all figures are in thousand dollars)

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<th>Annual Profit Per Acre</th>
<th>No. of Years</th>
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*Net annual income/acre = $127.00
Figure 3. Effect of Sprinkler and Lateral Spacings on the Total Annual Cost per Acre (First Run)
Second Run

In the second run of the program, the input data is the same as presented in Appendix H; in addition the diameters of the main line segments are read into the program. These diameters have been increased by 2 inches over those diameters calculated in the first run. The steps of calculating the diameters of the main line segments have been omitted from the program. The results of this run are presented in Tables 8, 9, and 10 which show the design of the main line, the power requirements, and the economic analysis of the whole system, respectively. Figure 4 shows the effect of sprinkler and lateral spacings on the total annual cost per acre in that case.

Third Run

In the third run of the program, the input data is the same as presented in Appendix H; in addition the diameters of the main line segments are read into the program. These diameters have been decreased by 2 inches from those diameters calculated in the first run. The steps of calculating the diameters of the main line segments have been omitted from the program. The results of this run are presented in Tables 11, 12, and 13 which show the design of the main line, the power requirements, and the economic analysis of the whole system, respectively. Figure 5 shows the effect
### Table 8

**Design of Main Line (Second Run)**

<table>
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<th>SL (ft)</th>
<th>SM (ft)</th>
<th>Diameter of Main Line Segments (inches)</th>
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### Table 9

Power Requirements (Second Run)

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<th>SL (ft)</th>
<th>SM (ft)</th>
<th>Head on the Pump (ft)</th>
<th>Total Flow (gpm)</th>
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<th>Brake Horsepower (HP)</th>
<th>Required Horsepower (HP)</th>
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Table 10

Economic Analysis (Second Run)*

(all figures are in thousand dollars)

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*Net annual income/acre = $127.00
Figure 4. Effect of Sprinkler and Lateral Spacings on the Total Annual Cost per Acre (Second Run)
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<th>SL (ft)</th>
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<th>Diameter of Main Line Segments (inches)</th>
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Table 11
Design of Main Line (Third Run)
Table 12
Power Requirements (Third Run)

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Table 13
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(all figures are in thousand dollars)

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<th>Annual Cost</th>
<th>Annual Profit Per Acre</th>
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*Net annual income = $127.00
Figure 5. Effect of Sprinkler and Lateral Spacings on the Total Annual Cost per Acre (Third Run)
of sprinkler and lateral spacings on the total annual cost per acre in that case.

DISCUSSION

It is evident from running the program three times that the second run gives the optimum solution. The criterion for that is the overall total annual cost per acre. Tables 7, 10, and 13 which show the economic analysis support this conclusion along with Figures 3, 4, and 5 which show the effect of sprinkler and lateral spacings on the total annual cost per acre for the three runs. The sprinkler and lateral spacing combination 30 x 50 feet is found to be the one which gives the lowest annual cost per acre in the three runs. The second run gives the lowest annual cost per acre for this spacing (30 x 50 ft); this can be explained by Figure 6 which shows the main line annual cost, the pumping annual cost, and the combined annual cost for each of the three runs. The second run has the lowest combined annual cost which subsequently gives the lowest total annual cost per acre for the spacing 30 x 50 feet.

APPLICATION

With respect to the area of application, the two programs developed in this study are applicable to the newly sprinkler irrigated areas, where no specific spacing combination is recommended.
Figure 6. Optimum Solution Analysis, Considering Main Line, Pumping, and Combined Annual Costs (30 x 50 ft. spacing)
They are also applicable to sprinkler hand-move systems, with single size pipe laterals that run parallel to the contour lines and a main line which runs either up hill or level and is perpendicular to the laterals. The limitations on those two programs are that they can handle one area of land and a maximum of twelve laterals. Another disadvantage of these two programs is that PROGRAM-2 has to be run several times in order to establish the optimum solution.

SUGGESTIONS FOR FURTHER RESEARCH

Besides relaxing some of the assumptions, other possibilities for further research exist. One example would be the incorporation of more than one land area and more than one lateral size and length. Another example would be to modify the program to give the optimum solution directly without running it several times. Also the program could be modified to draw the main line profile. Many other clever possibilities exist due to the complexity and the numerous variables involved in the design of sprinkler irrigation systems.
Chapter 7

SUMMARY

The two programs developed in this study, PROGRAM-1 and PROGRAM-2, are to design the different components of the sprinkler irrigation hand-move systems for newly irrigated areas. The layout for these irrigation systems is such that the laterals run parallel to the contour lines, and the main line runs perpendicular to the laterals either up hill or level. PROGRAM-1 calculates the required flow from each sprinkler after adjusting the soil intake rate for land slope effect. It also calculates the required wetted diameter taking into consideration the effect of the average wind speed. PROGRAM-2 takes soil, plant, and climatic data as input. It also takes as input the specifications of the selected sprinkler heads, as determined by PROGRAM-1 output, and then determines and designs the following:

1. Crop peak daily consumptive use
2. Irrigation interval
3. Lateral operating hours
4. Number of lateral sets per day
5. Number of laterals
6. Size of lateral
7. Size of main line
8. Size of valves
9. Power requirements
10. Economic analysis

Several sprinkler and lateral spacing combinations can be tested in these two programs. The criterion for selecting a specific spacing combination is the total annual cost per acre. PROGRAM-2 has to be run several times in order to establish the optimum solution.
LITERATURE CITED
LITERATURE CITED

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Christiansen, J. E. 1941. The uniformity of application of water by sprinkler system. Agricultural Engineering 22:(3) 89-92.


Hanson, C. H., ed. 1972. Alfalfa science and technology. Published by the ASA, Number 15 in the Series of Agronomy, pp. 474.


Keller, J. 1965. Selection of economical pipe size for sprinkler irrigation systems. Transactions of the ASAE, 8:(2) 186-190,193.


APPENDIX A

PROGRAM-1 FLOW CHART
Figure 7

Flow Chart of PROGRAM-1
APPENDIX B

PROGRAM-1 VARIABLE GLOSSARY
AWS = average speed of prevailing winds (MPH)

D = soil depth (ft)

HC = soil holding capacity (in/ft)

IR = soil intake rate (in/hr)

IRA = adjusted soil intake rate (in/hr)

S = slope of land (percent)

SL = spacing of sprinklers on the lateral (ft)

SM = spacing of laterals on the main (ft)

ST1, ST2 = soil type

STX1, STX2 = soil texture

Q = flow of sprinkler (gpm)

WD = wetted diameter of sprinkler (ft)

WDL = wetted diameter of sprinkler in lateral direction (ft)

WDM = wetted diameter of sprinkler in main direction (ft)
APPENDIX C

PROGRAM-1 LISTING
PROGRAM TO DESIGN SPRINKLER IRRIGATION SYSTEMS

MAIN PROGRAM-1 TO FIND SPRINKLER HEAD SPECIFICATION

INPUT DATA CARDS INSTRUCTIONS

MAIN PROGRAM DATA:

1ST CARD : AVERAGE WIND SPEED 1-10

SOIL SUBROUTINE DATA:

2ND CARD TO 11TH CARD : SPACING OF SPRINKLERS ON THE LATERALS 1-10, SPACING OF LATERALS ON THE MAIN LINE 11-20

12TH CARD : SOIL TYPE 1-8, SOIL TEXTURE 9-16

13TH CARD : SOIL HOLDING CAPACITY 1-5, SOIL DEPTH 6-10, SOIL INTAKE RATE 11-15, SOIL SLOPE 16-20

COMMON ST(1), ST2, STX1, STX2, HC, D, IR, S, AWS, SL(10), SM(10)

REAL IR, IRA, HC

WRITE(108,10)

10 FORMAT("1", 27X, "SPRINKLER IRRIGATION DESIGN PROGRAM", //21X, "PROGRAM 1-1 TO FIND SPRINKLER HEAD SPECIFICATIONS", //, 1X, "INPUT INFORMATION 1/18(-)")

READ(105,20) AWS

20 FORMAT(F)

DO 30 I = 1, 10

30 READ(105,40) SL(I), SM(I)

40 FORMAT(2F)

WRITE(108,50) AWS

50 FORMAT(1X, "AVERAGE WIND SPEED=", F5.2, 2X, "MPH")

CALL SOIL

WRITE(108,60) ST(1), ST2, STX1, STX2, HC, D, IR, S


C ADJUST IR FOR SLOPE EFFECT

IF(S.GT.20) IRA = 0.25 * IR : GO TO 70
IF(S.GE.13) IRA = 0.40 * IR : GO TO 70
IF(S.GE.9) IRA = 0.60 * IR : GO TO 70
IF(S.GE.6) IRA = 0.80 * IR : GO TO 70
IF(S.LE.5) IRA = IR

70 WRITE(108,80) IRA

80 FORMAT(1X, "ADJUSTED INTAKE RATE=", F5.3, 4X, "IN/HOUR")

C CALCULATE SPRINKLER HEAD FLOW IN GPM

DO 100 I = 1, 10

Q(I) = (IRA * SL(I) * SM(I)) / 96.3

C CALCULATE SPRINKLER HEAD WETTED DIAMETER

IF(AWS.GT.10) WDL(I) = SL(I) / 0.30 ; WDM(I) = SM(I) / 0.50 : GO TO 90

100 FORMAT(1X, "Q(I)=")

STOP
IF(AW.S.GE.7) WDL(I)=SL(I)/0.43 \( \cdot \) WDM(I)=SM(I)/0.60 \; \text{GO TO 90}

IF(AW.S.GE.0) WDL(I)=SL(I)/0.40 \; \text{GO TO 90}

90 IF(WDL(I).LT.WDM(I)) \( \text{GO TO 100} \)

WDC(I)=WDM(I)

100 CONTINUE

WRITE(10A, 110)

110 FORMAT("1X, 'PROGRAM OUTPUT :', 1X, 10('-'), 3X, 'SPRINKLER HEAD SPECIFICATIONS')

WRITE(10A, 120)


100 3X, 'WD', 3X, (FTXFT)', 4X, 'GPM', 7X, (F'), 4X, 4X, 10('-'))

DO 130 I=1,10

130 WRITE(10A, 140) SL(I), SM(I), Q(I), WD(I)

140 FORMAT("//, 3X, 12X, I, 10X, 13X, F5.2, 4X, F6.4")

END

SUBROUTINE TO INPUT SOIL DATA

COMMON ST1, ST2, STX1, STX2, HC, D, IR, S

REAL IR, HC

READ(105, 7) ST1, ST2, STX1, STX2

7 FORMAT(2A4, 5X, 2A4)

READ(105, 8) HC, D, IR, S

8 FORMAT(4F5.2)

RETURN

END
APPENDIX D

PROGRAM-1 OUTPUT
SPRINKLER IRRIGATION DESIGN PROGRAM

PROGRAM-1 TO FIND SPRINKLER HEAD SPECIFICATIONS

INPUT INFORMATION

AVERAGE WIND SPEED = 9.30 MPH

SOIL DATA:
TYPE: SILT CLAY
INTAKE RATE = 1.30 IN/HOUR
DEPTH = 0.60 FT

TEXTURE: MEDIUM
HOLDING CAPACITY = 3.10 IN/FOOT
SLOPE = 3.00 %

ADJUSTED INTAKE RATE = 0.600 IN/HOUR
## SPRINKLER HEAD SPECIFICATIONS

<table>
<thead>
<tr>
<th>SPACING (FT X FT)</th>
<th>FLOW Q (GPM)</th>
<th>WETTED DIA NO (FT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 x 30</td>
<td>5.61</td>
<td>75.0000</td>
</tr>
<tr>
<td>30 x 40</td>
<td>7.48</td>
<td>75.0000</td>
</tr>
<tr>
<td>30 x 50</td>
<td>9.35</td>
<td>83.3333</td>
</tr>
<tr>
<td>30 x 60</td>
<td>11.21</td>
<td>100.0000</td>
</tr>
<tr>
<td>40 x 40</td>
<td>9.97</td>
<td>100.0000</td>
</tr>
<tr>
<td>40 x 50</td>
<td>12.46</td>
<td>100.0000</td>
</tr>
<tr>
<td>40 x 60</td>
<td>14.95</td>
<td>100.0000</td>
</tr>
<tr>
<td>50 x 50</td>
<td>15.58</td>
<td>125.0000</td>
</tr>
<tr>
<td>50 x 60</td>
<td>18.69</td>
<td>125.0000</td>
</tr>
<tr>
<td>60 x 60</td>
<td>22.43</td>
<td>150.0000</td>
</tr>
</tbody>
</table>
79

Figure 8
Flow Chart of PROGRAM-2
Figure 9
Flow Chart of SUBROUTINE CLIMATE
APPENDIX F

PROGRAM-2 VARIABLE GLOSSARY
1) Main Program

WL = leaching requirements (in)
EFF = efficiency of sprinkler system
AREA = area to be irrigated (sq. ft)
LL = length of lateral (ft)
LM = length of main line (ft)
C = Hazen-Williams constant
M = exponent in Hazen-Williams equation for head loss in pipes
ELEVO = elevation at the center line of the pump (ft)
HS = suction head on the pump (ft)
PEFF = efficiency of pump
SNIR = net seasonal irrigation requirements (in)
CKWH = cost per kwh
CDEMAND = cost per H.P. demand
EEFF = efficiency of motor
PDU = crop peak daily use (in/day)
AVGPEAK = average daily peak of crop consumptive use as calculated in subroutine CLIMATE (in/day)
D = depth of soil (ft)
RZ = crop root zone depth (ft)
NMR = net moisture replaced each irrigation (in)
AMC = available moisture content (in)
PER = percent of available moisture content to be replaced each irrigation
GMR = gross moisture replaced each irrigation (in)
IRRINT,IRRI = irrigation interval (days)
LOH = lateral operating hours
AR = sprinkler application rate (in/hr)
LSET = number of lateral sets per day
NOL,NL = number of laterals
HL = allowable head loss in the lateral (ft)
NS = number of sprinklers per lateral
SL = spacing of sprinklers on the lateral (ft)
SUMNS = summation term
FAC = factor
F = factor to account for multiple outlets in Christiansen's procedure for designing pipes with multiple outlets
DIA,DL = diameter of lateral (in)
V = velocity of flow in the lateral (fps)
HLA = actual head loss in the lateral (ft)
IDM1, . . . , IDM6 = diameters of main line segments (in)
H1, . . . , H6 = total energy head elevation at the main line segments
HLA1, ..., HLA6 = actual head loss in the main line segments (ft)
LM1, ..., LM6 = length of main line segments (ft)
V1, ..., V6 = velocity of flow in main line segments (fps)
PO = pressure at the inlet of the lateral (psi)
HO = head at the inlet of the lateral (ft)
Q1, ..., Q6 = flow in the main line segments (gpm)
LML = length irrigated by one lateral (ft)
HLL = head loss in the main line segments of length equal LML (ft)
HE = difference in elevation in the main line (ft)
RIRRP = irrigation period (days)
SM = spacing of laterals on the main line (ft)
HT = total energy head at the pump (ft)
HTP = total head on the pump (ft)
WHP = water horsepower
BHP = brake horsepower
DFCV = diameter of flow control valve (in)
DCHV = diameter of check valve (in)
DARV = diameter of air release and vacuum valve (in)
CPUMP = cost of pump and power unit
CIDM1, ..., CIDM6 = cost of pipe diameters of main line segments
ID = priced pipe diameters of main line segments (in)
IDR = diameter of main line risers (in)
IRISER = cost of main line risers
CIDR = cost of pipe diameter of riser
CML = total cost of main line including installation
IDL = cost of laterals
CLATERAL = total cost of laterals
TCSPR = total cost of sprinkler head
CSPR = cost of sprinkler head
TCOST = total cost of the sprinkler system
CPACRE = cost per acre
AFC = annual fixed costs for the system
AMLC = annual fixed costs for the main line
SHOURS = operating hours during the season
APC = annual power costs
APMC = annual pumping costs
ALC = annual lubrication costs
AMNC = annual maintenance costs
NIRR = number of irrigations during the season
ALBC = annual labor costs
ATIC = annual taxes and insurance costs
AOMC = annual operation and maintenance costs
TAC = total annual costs for the system
ACPA = total annual costs per acre
AFARC = annual farming costs per acre
AIM = annual income per acre
NAIN = net annual income per acre
APR = annual profit or loss per acre
YEARS = number of years needed to pay for the system

2) SUBROUTINE SOIL
ST1,ST2 = soil type
STX1,STX2 = soil texture
HC = soil holding capacity (in/ft)
D = soil depth (ft)
IR = soil intake rate (in/hr)
S = slope of land (percent)

3) SUBROUTINE PLANT
N = name of crop
R2 = crop root zone depth (ft)

4) SUBROUTINE CLIMATE
E = average elevation of land (ft)
KC = Jensen-Haise crop factor
C2 = Jensen-Haise constant
DAY = day number in the month of July
TX = mean maximum daily temperature (°F)
TN = mean minimum daily temperature (°F)
RS = mean daily solar radiation (langley or cal cm⁻²)
PP = effective mean daily precipitation (in)
T = mean daily temperature (°F)
TXC = mean maximum daily temperature (°C)
TNC = mean minimum daily temperature (°C)
PSX = saturated vapor pressure at TX (mm Hg)
PSN = saturated vapor pressure at TN (mm Hg)
CH = a humidity index
Cl = constant depends on kind of crop
CT = temperature coefficient (°F)⁻¹
TO = temperature intercept (°F)
RSS = daily solar radian (in)
ETP = potential evapotranspiration (inches/day)
ET = crop evapotranspiration (inches/day)
CU = crop daily consumptive use (inches/day)
PEAK = peak daily consumptive use (inches/day)
AVGPEAK = average peak daily consumptive use (inches/day)

5) SUBROUTINE SPRINKLER
TY1, TY2, TY3 = type of sprinkler
Q = flow of sprinkler (gpm)
WD  = wetted diameter of sprinkler (ft)
PRE  = operating pressure of sprinkler (psi)
ND  = nozzle diameter of sprinkler (inches)
AR  = application rate of sprinkler (in/hr)
SL,SM,CSPR = as defined earlier
APPENDIX G

PROGRAM-2 LISTING
TO DO ECONOMIC ANALYSIS
INPUT DATA CARDS INSTRUCTIONS
MAIN PROGRAM DATA:
1ST CARD: LEACHING REQUIREMENTS 1-5, SPRINKLER SYSTEM EFF. 6-10
2ND CARD: THE VALUES OF AREA TO BE IRRIGATED, LENGTH OF LATERAL,
LENGTH OF MAIN LINE, AND HAZEN-WILLIAMS COEFF. (C) ARE INTEGERS.
THEY ARE READ IN (I) FORMAT, PUNCH THEIR VALUES SEPARATED BY COMMAS
EXPONENT (M) NEXT 5 COLUMNS, ELEVATION AT THE PUMP 10 COLUMNS,
SUCTION HEAD AT THE PUMP 10 COLUMNS.
3RD CARD: PUMP EFF. 1-10, NET SEASONAL IRRIGATION REQUIREMENTS
11-20, COST PER KWH 21-30, COST PER DEMAND 31-40, ELECTRICAL
MOTOR EFF. 41-50.

SUBROUTINES DATA
SOIL SUBROUTINE DATA:
4TH CARD: SOIL TYPE 1-8, SOIL TEXTURE 9-16;
5TH CARD: SOIL HOLDING CAPACITY 1-5, SOIL DEPTH 6-10,
SOIL INTAKE RATE 11-15, SOIL SLOPE 16-20.

PLANT SUBROUTINE DATA:

CLIMATE SUBROUTINE DATA:
7TH CARD: AVERAGE ELEVATION 1-10, CROP FACTOR (KC) 11-20,
CONSTANT (C2) 21-30.
8TH CARD TO 38TH CARD: THE VALUES OF DAY, MAX. DAILY TEMP., MIN.
DAILY TEMP., AND DAILY SOLAR RADIATION ARE READ IN (F) FORMAT.
PUNCH THEIR VALUES AS THEY ARE SEPARATED BY COMMAS. EFFECTIVE
PRECIPITATION THE NEXT 4 COLUMNS.

SUBROUTINE SPRINKLER DATA:
39TH CARD TO 48TH CARD: TYPE OF SPRINKLER 1-12, FLOW OF SPRINKLER
13-22, WETTED DIA. OF SPRINKLER 23-32, SPRINKLER OPERATING
PRESSURE 33-42, NOZZLE DIA. 43-52, SPACING OF SPRINKLERS ON THE
LATERAL 53-62, SPACING OF LATERALS ON TH MAIN LINE 63-72, COST OF
SPRINKLER 73-82.

COMMON ST1, ST2, STX1, STX2, HC, 0, IR, S, AWS, ML, L, EFF, E, KC, C2, RZ, N(2), AVG
PEAK, QC(10), WDC10, SLC10, SM(10), PR(10), NOC10, AR(10), ARE, LL, LW, C,
1M, ELEV0, H, PEFF, SNIR, CKWH, CDemand, EFEF, TY1(10), TY2(10), TY3(10), CSP
READ IN DATA
READ(105,10) WL,EFF
10 FORMAT(2F5.3)
READ(105,20) AREA,LL,LM,C,M,ELEV0,HS
20 FORMAT(1F5.3)
READ(105,30) PEFF,SNIR,CKWH,COE,M,EFF
30 FORMAT(5F10.4)

CALL SUBROUTINES
CALL SOIL
CALL CLIMATE
CALL SPRINKLER
CALL INPUT

WRITE(108,32) WL,EFF,AREA,LL,LM,C,M,ELEV0,HS
32 FORMAT(1)
   2X,"MAIN PROGRAM DATA",/;
   2X,17(""," ");/;
   2X,"LENGTH OF LATERAL" = "1,2X,"FT";/;
   2X,"LENGTH OF MAINLINE" = "1,2X,"FT";/;
   2X,"HAZEN-WILLIAMS COEFF.(C) = "I,1/;
   2X,"EXponent" = "F5.2/;
   2X,"elevation at the pump =" = "F5.2/;
   2X,"suction head on the pump =" = "F5.2/;
   2X,"HEIGHT OF PUMP =" = "F5.2/;
   2X,"HEIGHT OF PUMP =" = "F5.2/;
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   2X,"HEIGHT OF PUMP =" = "F5.2/;
   2X,"HEIGHT OF PUMP =" = "F5.2/;
   2X,"HEIGHT OF PUMP =" = "F5.2/;
WRITE(108,33) PEFF,CKWH,CDemand,EEFF,SNIR
33 FORMAT(15x, 2x, "PUMP EFFICIENCY =","F5.2",1x, 2x, "DEMAND COST","F3.2", 2x, "COST PER KWH","F5.2", 2x, "$/HP","F5.2", 2x, "Effe. of Electrical Motor =","F5.2", 2x, "NET SEASONAL"
1L IRRIGATION REQUIREMENTS=","F6.2", 2x, "INCHES")

C
C CALCULATE PEAK DAILY USE FOR CROP
PDU=AVGPEAK+WL
C
C CALCULATE NET AND GROSS MOISTURE TO BE REPLACED
IF(D. LE. RZ) RZ=0
AMC=HC*RZ
IF(RZ.LE.3) NMR=AMC*PER(1) ; GO TO 140
IF(RZ.LE.5) NMR=AMC*PER(2) ; GO TO 140
IF(RZ.LE.9) NMR=AMC*PER(3)
140 GMR=NMR/EFF
C
C CALCULATE IRRIGATION INTERVAL
IRRINT=NMR/PDU
X=IRRINT+.01
IRRIN=IDINT(X)
WRITE(108,34) PEAK, AVGPEAK, PDU, AMC, NMR, GMR, IRRIN
34 FORMAT(15x, 2x, "PROGRAM - 2 OUTPUT =","F6.3", 2x, "INCHES/DAY",1x, 2x, "AVERAGE CON"
1SIMPTIVE USE=","F6.3", 2x, "INCHES/DAY",1x, 2x, "PEAK DAILY USE"
1SIMPTIVE USE=","F6.3", 2x, "INCHES/DAY",1x, 2x, "AVAILABLE MOISTURE CONTENT=","F6.3", 2x, "NET MOISTURE REPLACED=","F6.3", 2x, "GROSS MOISTURE REPLACED=",X, I, 5X, "DAYS")
C
C START A LOOP FOR CALCULATING THE COMPONENTS OF THE DIFFERENT SYSTEMS
DO 350 I=1,10
C
C CALCULATE LATERAL OPERATING HOURS, NUMBER OF SETS PER LATERAL PER DAY,
C NUMBER OF LATERALS, IRRIGATION PERIOD
LOH(I)=GMR/ARC(I)
IF(LOHI(I).LE.7) LSET(I)=3 ; GO TO 150
IF(LOHI(I).LE.11) LSET(I)=2 ; GO TO 150
LSET(I)=1
150 NOL(I)=AREA/(LSET(I)*SM(I)*IRRIN*LL)
Y=NOL(I)+.90
NL(I)=IDINT(Y)
C DESIGN OF LATERAL
HL(I)=(23.4/100)*PRE(I)*.31
NSC(I)=(CL-SL(I)/2)/SL(I)+1
SUMNS(I)=(NS(I)**M)/2
DO 160 J=1,NS(I)-1
FAC(J)=J**M
SUMNS(I)=SUMNS(I)+FAC(J)
160 CONTINUE

F(I)=(SUMNS(I))/(NS(I)**(M+1))
DIA(I)=(10.43+F(I)*LL*(Q(I)*NS(I))**M)/(HL(I)*(C**M))**((1/4.87)
Z=DIA(I)+0.90
DL(I)=IDINT(Z)
IF (DL(I).GT.5) GO TO 340
V(I)=(Q(I)*NS(I)*4*144)/(448.8*3.1416*(DL(I)**2))
HLA(I)=(10.43+F(I)*LL*(Q(I)*NS(I))**M)/(C**M*(DL(I)**4.87))

C DESIGN OF MAIN PIPELINE

IDM1(I)=IDM2(I)=IDM3(I)=IDM4(I)=IDM5(I)=IDM6(I)=0
H1(I)=H2(I)=H3(I)=H4(I)=H5(I)=H6(I)=0
HLA(I)=HLA2(I)=HLA3(I)=HLA4(I)=HLA5(I)=HLA6(I)=0
LM1(I)=LM2(I)=LM3(I)=LM4(I)=LM5(I)=LM6(I)=0
V1(I)=V2(I)=V3(I)=V4(I)=V5(I)=V6(I)=0
P0(I)=PRE(I)+(0.75*HLA(I))/2.31

H0(I)=V(I)**2.31
Q1(I)=(Q(I)*NS(I)+NL(I)
LM1(I)=AREA/(LL*NL(I))
HLL(I)=(1/100)*LM1(I)
HE(I)=(S/100)*LM
RIRRPA(I)=LM1(I)/LM1(I)*LSET(I))

C IF(NL(I).EQ.2) GO TO 170
170 LM1(I)=LM-(LML(I)**(NL(I)/2)-1))
GO TO 190
190 IF (NL(I).EQ.10) GO TO 170
180 LM1(I)=LM-(LML(I)**(NL(I)-1))/2)
GO TO 190

190 LM1(I)=LM-(LML(I)**(NL(I)-1))/2)
HLM1(I)=(10.43*LM1(I)**(Q1(I))**M)/(HL1(I)**(C**M))**((1/4.87)
1)*1

HLA1(I)=(10.43*LM1(I)**(Q1(I))**M)/(C**M)*IDM1(I)**4.87))
V1(I)=(Q1(I)**4*144)/(448.8*3.1416*(IDM1(I)**2))

C IF(NL(I).EQ.2) GO TO 260
IF(NL(I).EQ.3) GO TO 200
Q2(I)=Q(I)*NS(I)*(NL(I)-2)
GO TO 210
200 Q2(I)=Q(I)*NS(I)*(NL(I)-1)
210 LM2(I)=LML(I)
IDM2(I)=((10.43*LM2(I)*(Q2(I)**M))/(HLL(I)*(C**Y)))**(1/4.87)
10R.IDM2(I).EQ.15.OR.IDM2(I).EQ.17.OR.IDM2(I).EQ.19) IDM2(I)=IDM2(I)+1

HLA2(I)=(10.43*LM2(I)*(Q2(I)**M))/(HLL(I)*(C**M))**(1/4.87)
V2(I)=(Q2(I)**4*144)/(448.8**3.1416*(IDM2(I)**4.87))
IF(NL(I)**.GE.6) GO TO 220
HT(I)=ELEV0+HE(I)+H0(I)+HLA1(I)+HLA2(I)+HS
H1(I)=HT(I)-HLA1(I)
H2(I)=H1(I)-HLA2(I)
GO TO 290

220 Q3(I)=Q(I)*NS(I)*(NL(I)-4)
LM3(I)=LML(I)
IDM3(I)=(10.43*LM3(I)*(Q3(I)**M))/(HLL(I)*(C**M))**(1/4.87)
10R.IDM3(I).EQ.15.OR.IDM3(I).EQ.17.OR.IDM3(I).EQ.19) IDM3(I)=IDM3(I)+1

HLA3(I)=(10.43*LM3(I)*(Q3(I)**M))/(HLL(I)*(C**M))**(1/4.87)
V3(I)=(Q3(I)**4*144)/(448.8**3.1416*(IDM3(I)**4.87))
IF(NL(I)**.GE.6) GO TO 230
HT(I)=ELEV0+HEC(I)+H0(I)+HLA1(I)+HLA2(I)+HLA3(I)+HS
H1(I)=HT(I)-HLA1(I)
H2(I)=H1(I)-HLA2(I)
H3(I)=H2(I)-HLA3(I)
GO TO 290

230 Q4(I)=Q(I)*NS(I)*(NL(I)-6)
LM4(I)=LML(I)
IDM4(I)=(10.43*LM4(I)*(Q4(I)**M))/(HLL(I)*(C**M))**(1/4.87)

HLA4(I)=(10.43*LM4(I)*(Q4(I)**M))/(HLL(I)*(C**M))**(1/4.87)
V4(I)=(Q4(I)**4*144)/(448.8**3.1416*(IDM4(I)**4.87))
IF(NL(I)**.GE.8) GO TO 240
HT(I)=ELEV0+HEC(I)+H0(I)+HLA1(I)+HLA2(I)+HLA3(I)+HLA4(I)+HS
H1(I)=HT(I)-HLA1(I)
H2(I)=H1(I)-HLA2(I)
H3(I)=H2(I)-HLA3(I)
H4(I)=H3(I)-HLA4(I)
GO TO 290

240 Q5(I)=Q(I)*NS(I)*(NL(I)-8)
LM5(I)=LML(I)
IDM5(I)=(10.43*LM5(I)*(Q5(I)**M))/(HLL(I)*(C**M))**(1/4.87)

HLA5(I)=(10.43*LM5(I)*(Q5(I)**M))/(HLL(I)*(C**M))**(1/4.87)
\[ V5(I) = \frac{(L5(I) \times 4 \times 144)}{(448.8 \times 3.1416 \times (10M5(I)^2))} \]

IF \(NL(I) \geq 16\) GO TO 260

HT(I) = \(ELEVO + HE(I) + HC(I) + HLA1(I) + HLA2(I) + HLA3(I) + HLA4(I) + HLA5(I) + HS\)

H1(I) = HT(I) - HLA1(I)
H2(I) = H1(I) - HLA2(I)
H3(I) = H2(I) - HLA3(I)
H4(I) = H3(I) - HLA4(I)
H5(I) = H4(I) - HLA5(I)

GO TO 290

250 Q6(I) = \(Q(I) \times NL(I) - 10\)

LM6(I) = \(LML(I) \times 2\)

IDM6(I) = \((10.43 \times LM6(I) \times Q6(I)) / (448.8 \times 3.1416 \times (10M6(I)^2))\)

HT(I) = \(ELEVO + HE(I) + HC(I) + HLA1(I) + HLA2(I) + HLA3(I) + HLA4(I) + HLA5(I) + HS\)

H1(I) = HT(I) - HLA1(I)
H2(I) = H1(I) - HLA2(I)
H3(I) = H2(I) - HLA3(I)
H4(I) = H3(I) - HLA4(I)
H5(I) = H4(I) - HLA5(I)

GO TO 290

260 Q2(I) = \(Q(I) \times NL(I) - 1\)

LM2(I) = \(LML(I) \times 2\)

IDM2(I) = \((10.43 \times LM2(I) \times Q2(I)) / (448.8 \times 3.1416 \times (10M2(I)^2))\)

HT(I) = \(ELEVO + HE(I) + HC(I) + HLA1(I) + HLA2(I) + HLA3(I) + HLA4(I) + HLA5(I) + HS\)

H1(I) = HT(I) - HLA1(I)
H2(I) = H1(I) - HLA2(I)
H3(I) = H2(I) - HLA3(I)
H4(I) = H3(I) - HLA4(I)
H5(I) = H4(I) - HLA5(I)

GO TO 290

270 WRITE(106,260)

260 FORMAT('NUMBER OF LATERALS IS GREATER THAN 12 ; THIS PROGRAM CAN NOT TREAT MORE THAN 12 LATERALS ; YOU SHOULD MODIFY THIS PROGRAM')

GO TO 350

C CALCULATING POWER REQUIREMENTS
C CALCULATE FIRST WATER HORSEPOWER
C

290 HTP(I) = HT(I) - ELEVO
\[ \text{WHP}(I) = \text{Q}(I) \times \text{HTP}(I) / 3960 \]

C Calculate Next Brake Horsepower

\[ \text{BHP}(I) = \text{WHP}(I) / \text{PEFF} \]

C Sizing of Different Valves

C Sizing of Flow Control Valve

\[ \text{DFCV}(I) = \text{IDM}1(I) \]

C Sizing of Check Valve

\[ \text{DCHV}(I) = \text{IDM}1(I) \]

C Sizing of Air Release and Vacuum Valves

\[ \text{IDM}1(I) \leq 4 \Rightarrow \text{DARV}(I) = 0.5 \Rightarrow \text{GO TO 295} \]

\[ \text{IDM}1(I) \geq 5 \Rightarrow \text{DARV}(I) = 1 \Rightarrow \text{GO TO 295} \]

\[ \text{DARV}(I) = 3 \]

C Economic Analysis of the Sprinkler Irrigation System

C Water Supply Cost is Excluded

C Cost of Pump and Power Unit Including Installation

C The Cost of Pump and Power Unit is Taken as a Lump Sum of $55/HP and

C It includes the Installation Cost. It can be Adjusted Afterwards

\[ \text{CPUMP}(I) = \text{BHP}(I) \times 55 \]

C Cost of Distribution System

C Cost of Mainline Including Installation

\[ \text{D} \text{O} 310 \text{ K} = 1.8 \]

\[ \text{IDM}1(I) \text{EQ.ID}(K) \Rightarrow \text{IDM}1(I) = \text{COST}(K) \]

\[ \text{IDM}2(I) \text{EQ.ID}(K) \Rightarrow \text{IDM}2(I) = \text{COST}(K) \]

\[ \text{IDM}3(I) \text{EQ.ID}(K) \Rightarrow \text{IDM}3(I) = \text{COST}(K) \]

\[ \text{IDM}4(I) \text{EQ.ID}(K) \Rightarrow \text{IDM}4(I) = \text{COST}(K) \]

\[ \text{IDM}5(I) \text{EQ.ID}(K) \Rightarrow \text{IDM}5(I) = \text{COST}(K) \]

\[ \text{IDM}6(I) \text{EQ.ID}(K) \Rightarrow \text{IDM}6(I) = \text{COST}(K) \]

300 CONTINUE

\[ \text{IDR}(I) = \text{D}(I) \]

\[ \text{DO} \text{ 310} \text{ K} = 1.4 \]

\[ \text{IF(IDR}(I) \text{EQ.IDR}(K)) \Rightarrow \text{IDR}(I) = \text{COSTR}(K) \]

310 CONTINUE

C Cost of Main Pipe Line Includes: Cost of Steel Pipes, Risers Cost,

C Miscellaneous Fittings Cost (Estimated as 2% of the Steel Pipes Cost),

\[ \text{CML}(I) = (\text{IDM}1(I) \times \text{COST}(1)) + (\text{LM}2(I) \times \text{COST}(2)) + (\text{LM}3(I) \times \text{COST}(3)) + (\text{LM}4(I) \times \text{COST}(4)) + (\text{LM}5(I) \times \text{COST}(5)) + (\text{LM}6(I) \times \text{COST}(6)) \times 0.1 \times (\text{IDM}1(I) \times \text{COST}(I)) \times 0.1241 \]

AMLC(I) = CML(I) \times 0.1241
C COST OF LATERALS EXCLUDING SPRINKLERS
DO 320 K=1,4
   IF(CDL(K).EQ.IDL(K)) CDL(K)=CDL(K)
320 CONTINUE
CLATERAL(I)=((LL*CDL(I))*NL(I))

C COST OF SPRINKLERS
TCSPR(I)=CSPR(I)*NS(I)*NL(I)

C TOTAL COST OF SYSTEM AND COST PER ACRE IN DOLLARS
TOST(I) =CPUMP(I)+CML(I)+CLATERAL(I)+TCSPR(I)
CPACRE(I)=TCOST(I)/(AREA/43560)

C ANNUAL FIXED COST
C ASSUMING THE AVERAGE LIFE OF SYSTEM 15 YEARS AND 9% INTEREST
AFC(I)=TCOST(I)*0.1241

C ANNUAL OPERATION AND MAINTENANCE COST
C CALCULATING SEASONAL OPERATING HOURS OF THE SYSTEM
SHOURS(I)=((SNIR/(12*EFF))*AREA)/(CAREA/43560)*60*60

C ANNUAL POWER COST
C ASSUME ELECTRICAL POWER
EHP(I)=BHP(I)*EFF
APC(I)=KWH*SHOURS(I)*EHP(I)*0.746+(Demand*EHP(I))
C NOTE THAT EHP(I) SHOULD BE ADJUSTED FOR THE AVAILABLE ELECTRICAL MOTOR
C HORSEPOWER
APMCC(I)=CPUMP(I)*0.1241+APC(I)

C LUBRICATION ANNUAL COST
C FOR ELECTRICAL POWER MOTOR COST IS $0.67/100 HOURS
ALC(I)=(0.67/100)*SHOURS(I)

C MAINTENANCE ANNUAL COST
C ANNUAL MAINTENANCE COST FOR HAND-MOVE SPRINKLER SYSTEM IS ASSUMED 2%
C OF THE EQUIPMENT INITIAL COST
AMNC(I)=(2/100)*((CPUMP(I)/1.10)+CML(I)-((IDM1(I)*LM1(I))+(IDM2(I)*LM2(I))+(IDM3(I)*LM3(I))+(IDM4(I)*LM4(I))+(IDM5(I)*LM5(I))+(IDM6(I)*LM6(I))))*0.10+CLATERAL(I)+TCSPR(I)

C LABOR ANNUAL COST
C ASSUME LABOR FOR HAND-MOVE SPRINKLER SYSTEM 0.85 HRS/ACRE/IRRIGATION,
C AND LABOR COST $2.00/HR
ALBC(I)=2.00*0.85*(AREA/43560)*NIRR

C TAXES AND INSURANCE
C ANNUAL TAXES AND INSURANCE COST IS ASSUMED AS 2% OF THE EQUIPMENT
C INITIAL COST
ATIC(I)=(2/100)*((CPUMP(I)/1.10)+CML(I)-((IDM1(I)*LM1(I))+(IDM2(I)*LM2(I))+(IDM3(I)*LM3(I))+(IDM4(I)*LM4(I))+(IDM5(I)*LM5(I))+(IDM6(I)*LM6(I)))+CML(I))
TOTAL ANNUAL OPERATION AND MAINTENANCE COST

\[ \text{AMC}(I) = \text{APC}(I) + \text{ALC}(I) + \text{AMC}(I) + \text{ALC}(I) + \text{ATIC}(I) \]

TOTAL ANNUAL COST FOR THE SYSTEM EQUAL ANNUAL FIXED COST PLUS TOTAL OPERATION AND MAINTENANCE COST

\[ \text{TAC}(I) = \text{AFC}(I) + \text{AMC}(I) \]

TOTAL ANNUAL COST PER ACRE

\[ \text{ACPA}(I) = \frac{\text{TAC}(I)}{\text{AREA}/43560} \]

ANNUAL FARMING COST PER ACRE

This includes fertilisers and harvesting; assume 6 tons of alfalfa production per acre per year.

\[ \text{AFARC} = \text{AFC}(I) \times 6 \]

ANNUAL INCOME, assume $40.00 per ton of alfalfa

\[ \text{AIN} = 40.00 \times 6 \]

ANNUAL NET INCOME PER ACRE PER YEAR

\[ \text{AIN} = \text{AIN} - \text{ACPA}(I) \]

ANNUAL PROFIT OR LOSS, (MINUS SIGN MEANS LOSS)

\[ \text{APR}(I) = \text{AIN} - \text{ACPA}(I) \]

CALCULATE HOW MANY YEARS ARE NEEDED TO PAY FOR THE SYSTEM, IF THERE IS A PROFIT

\[ \text{IF}((\text{APR}(I) \leq 0.00)) \text{ YEARS}(I) = 0.00 \; \text{GOTO 330} \]

\[ \text{YEARS}(I) = \text{CPA}(I) / \text{APR}(I) \]

330 WRITE(108, 40) SL(I), SM(I), LQH(I), LSET(I), NL(I), NS(I), DL(I), HL(I), V1(I), V2(I), V3(I), V4(I), V5(I), V6(I)
WRITE(108, 90) DFCV(CI), DCHV(CI), DARVIC
WRITE(108, 100) HTP(V), Q1(I), WHP(I), HPP(I), EHP(I)
WRITE(108, 110) CPUMP(I), CMLCI), CLATERAL(I), TCSPR(I), TCOST(I), CPAcre(107)
WRITE(108, 120) AFC(I), AOMC(I), TAC(I), ACPI(I), NAIN, APR(I), YEARS(I)
WRITE(108, 121) ALMC(I), AMPC(I)
121 FORMAt(/, 2X, "ANNUAL MAIN LINE COST =", 2X, F10.2, /, 2X, "ANNUAL PUMPING 1 COST =", 2X, F10.2)
GO TO 350
340 WRITE(108, 130)
130 FORMAT(/, 1X, "LATERAL DIAMETER IS GREATER THAN 5 INCHES. IT IS NOT PRACTICAL FOR THE HAND-MOVE SYSTEMS")
350 CONTINUE
END
SUBROUTINE TO INPUT SOIL DATA
SUBROUTINE SOIL
COMMON ST1, ST2, STX1, STX2, HC, D, IR, S, AWS, W, EFF, E, KC, C2, RZ, N(C), AVG-P
READ(105, 7) ST1, ST2, STX1, STX2
READ(105, 8) HC, D, IR, S
RETURN
END
C SUBROUTINE TO INPUT PLANT DATA
SUBROUTINE CLIMATE
COMMON SH1, SH2, SHX, SHY, IR, S, AWS, WL, EFF, E, KC, C2, RZ, N, C, AVCP
READ(105, 6) (NCI, I=1, 2), RZ
FORMAT(2A4, F5.2)
RETURN
END

C SUBROUTINE TO INPUT CLIMATIC DATA AND CALCULATE PEAK CONSUMPTIVE USE
SUBROUTINE CLIMATE
COMMON SH1, SH2, SHX, SHY, IR, S, AWS, WL, EFF, E, KC, C2, RZ, N, C, AVCP
READ(105, 6) (NCI, I=1, 2), RZ
FORMAT(2A4, F5.2)
RETURN
END

DO 15 I=1, 31
READ(105, 6) DAY(I), TX(I), TN(I), RS(I), PP(I)
FORMAT(4F10.2)
T(I) = (TX(I) + TN(I)) / 2
TXC(I) = (TX(I) - 32) * 5 / 9
TNC(I) = (TN(I) - 32) * 5 / 9
PSX(I) = 4.58 * EXP((25.04 * TXC(I)) / (TXC(I) * 273)) - 1
PSN(I) = 4.58 * EXP((25.04 * TNC(I)) / (TNC(I) * 273)) - 1
CH(I) = 37.5 / (0.5 * (TXC(I) - PSX(I)))
C1 = 68 - 1.6 * F / 1000
C2 = 0.625 * (C1 + 0.4) / (C1 - 2 * CH(I))
RSS(I) = RS(I) * 9.673
ETP(I) = C2 * T(I) * (T(I) + TO(I)) * RSS(I)
ETC(I) = KC * ETP(I)
CONTINUE
PEAK = 0
DO 25 I=1, 31
CU(I) = ETP(I) - PP(I)
IF (CU(I) + GT. PEAK) PEAK = CU(I); MAXI = I
CONTINUE
SUM = 0
DO 35 I = MAXI - 3, MAXI + 3
SUM = SUM + CU(I)
AVGPEAK = SUM / 7
RETURN
END

C SUBROUTINE TO INPUT SPRINKLER HEAD SPECIFICATIONS
SUBROUTINE SPRINKLER

15 CONTINUE
10 CONTINUE
25 CONTINUE
35 CONTINUE
RETURN
END
COMMON ST1, ST2, STX1, STX2, HC, D, IR, S, AWS, WL, EFF, E, KC, C2, RZ, N(2), AVGP
1EAK, Q(10), WDC(10), SL(10), SM(10), PRE(10), NDC(10), AR(10), AREA, LL, LM, G,
1M, ELEVO, HS, PEFF, SNR, CKWH, GDP, DEMAND, EFF, TY1(10), TY2(10), TY3(10), CSP
1RC(10),
REAL NMR, IRRINT, LOM(10), NOL(10), ND
C INPUT SPRINKLER HEAD SPECIFICATIONS AND SPACINGS
DO 45 I=1,10
READ(105,16) TY1(I), TY2(I), TY3(I), Q(I), WDC(I), PRE(I), NDC(I), SL(I), SM
1(I), CSPR(I)
16 FORMAT(3A4, 3F10.6, 3F10.4, 3F10.6)
ARC(I)=96.3*Q(I)/SL(I)*SM(I))
45 CONTINUE
RETURN
END
C SUBROUTINE TO WRITE THE INPUT INFORMATION
SUBROUTINE INPUT
COMMON ST1, ST2, STX1, STX2, HC, D, IR, S, AWS, WL, EFF, E, KC, C2, RZ, N(2), AVGP
1EAK, Q(10), WDC(10), SL(10), SM(10), PRE(10), NDC(10), AR(10), AREA, LL, LM, G,
1M, ELEVO, HS, PEFF, SNR, CKWH, GDP, DEMAND, EFF, TY1(10), TY2(10), TY3(10), CSP
1RC(10), PEAK, DAY(31), TX(31), TN(31), RSC(31), PP(31)
REAL ND, IR, HC
C WRITE(108, 11)
FORMAT('1', 27X, 'PROGRAM - 2', 5X, 'TO DESIGN LATERAL, MAIN LINE',
1, TO FIND POWER REQUIREMENTS', 19X, 'AND TO DO ECONOMIC ANALYSIS',
24X, 'INPUT INFORMATION', 18X, 'SLOPE =', F5.2, 2X, 'IN/HOUR ', 5X, 'TYPE:
1', F5.2, 2X, 'NAME OF CROP:', X, 12A4, 8X, 'ROOT ZONE DEPTH =', F5.2, 2X, 'FT',
2X, 'AVG\E', 10X, 'ELEVATION =', F10.2, 2X, 'CROP FACTOR =', F6.2)
WRITE(108, 31) (NC(1), I=1, 31)
WRITE(108, 41) E, KC, C2
41 FORMAT('1', 1X, 'CLIMATIC DATA', 2X, 'MIN TEMP', 2X, 'SOLAR RADIATION', 2X, 'PRCP',
I4, 'MAX TEMP', 2X, 'AMBIENT TEMP', 2X, 'INCHES', 2X, 3C, 1X, 15C, 1X, 15C)
11X, 'INCHES', 2X, 'AMBIENT TEMP', 2X, 'INCHES', 2X, 3C, 1X, 15C, 1X, 15C)
WRITE(108, 51) DAY(I), TX(I), TN(I), RSC(I), PP(I)
51 FORMAT(1, 2X, 14X, 18X, 18X, 18X, 18X, 18X)
61 CONTINUE
DO 61 I=1,31
WRITE(108,62)
62 FORMAT(1X,9X,'Q',6X,'WD',5X,'PRE',5X,'ND',5X,'SL',5X,'COST',/13X,'GPM',5X,'PSI',4X,'INCH',4X,'FT',5X,'FT',6X,'$',/2X,12('1--'),3X,5(1'--'),3X,4(1'--'),3X,5(1'--'),3X,4(1'--'),3X,4(1'--'),3X,4(1'--'))
DO 81 I=1,10
WRITE(108,71) TY1(I),TY2(I),TY3(I),Q(I),WD(I),PRE(I),ND(I),SL(I),$1MCI),CSPR(I)
71 FORMAT(1X,3A4,3X,F5.2,4X,5X,3X,F4.2,4X,5X,3X,F5.2)
81 CONTINUE
RETURN
END
APPENDIX H

PROGRAM-2 OUTPUT
PROGRAM - 2
TO DESIGN LATERAL, MAIN LINE, TO FIND POWER REQUIREMENTS
AND TO DO ECONOMIC ANALYSIS

INPUT INFORMATION

SOIL DATA

| TYPE: SILTCLAY | TEXTURE: MEDIUM |
| INTAKE RATE = .60 IN/HOUR | HOLDING CAPACITY = 1.30 IN/FOOT |
| DEPTH = 3.10 FT | SLOPE = 3.00 % |

PLANT DATA

| NAME OF CROP: ALFALFA | ROOT ZONE DEPTH = 5.00 FT |
### CLIMATIC DATA

- **Average Elevation:** 2660.00 ft
- **Jensen-Haise Constant (C2):** 13.00
- **Crop Factor:** 1.00

### CLIMATIC DATA FOR JULY (MEAN VALUES):

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<th>DAY</th>
<th>MAX. TEMP. (F)</th>
<th>MIN. TEMP. (F)</th>
<th>SOLAR RADIATION (LANGLEYS)</th>
<th>EFFECTIVE PRECIP. (INCHES)</th>
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### Sprinklers Data

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</table>
MAIN PROGRAM DATA

LEACHING REQUIREMENTS = 0.00 INCHES
EFF. OF SPRINKLER SYSTEM = 0.65
AREA TO BE IRRIGATED = 9735600 SQ. FT
LENGTH OF LATERAL = 1330 FT
LENGTH OF MAINLINE = 4060 FT
HAZEN-WILLIAMS COEF. (C) = 120
EXponent (M) = 1.35
ELEVATION AT THE PUMP = 2600 FT
SUCTION HEAD ON THE PUMP = 20 FT

PUMP EFFICIENCY = 0.81
COST PER KWH = 0.025 $
DEMAND COST = 0.30 $/HP
EFF. OF ELECTRICAL MOTOR = 0.95
NET SEASONAL IRRIGATION REQUIREMENTS = 22.14 INCHES
## Program - 2 Output

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<tr>
<th>Description</th>
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<tr>
<td>Consumptive Use</td>
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<td>Average Consumptive Use</td>
<td>0.268 Inches/Day</td>
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<tr>
<td>Peak Daily Use</td>
<td>0.266 Inches/Day</td>
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<tr>
<td>Available Moisture Content</td>
<td>4.030 Inches</td>
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<tr>
<td>Net Moisture Replaced</td>
<td>2.015 Inches</td>
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<tr>
<td>Gross Moisture Replaced</td>
<td>3.100 Inches</td>
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<tr>
<td>Irrigation Interval</td>
<td>7 Days</td>
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</table>
DESIGN OF LATERAL

- SPACINGS = 30.50 FT
- OPERATING HOURS = 5.131 HR
- NUMBER OF SETS/DAY = 3
- NUMBER OF LATERALS = 7
- NUMBER OF SPRINKLERS = 44
- DIAMETER = 5 INCHES
- HEAD LOSS = 24.32 FT
- VELOCITY OF FLOW = 0.77 FPS
- IRRIGATION PERIOD = 6.97 DAYS
- SPRINKLER APPL. RATE = .60 INCHES/HOUR
### DESIGN OF MAIN PIPE LINE

<table>
<thead>
<tr>
<th>DM1</th>
<th>DM2</th>
<th>DM3</th>
<th>DM4</th>
<th>DM5</th>
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<table>
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<tr>
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<th>H2</th>
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<table>
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### SIZING OF VALVES

- Dia of Flow Control Valve = 14.00 inches
- Dia of Air Release Valve = 4.00 inches
- Dia of Check Valve = 14.00 inches

### POWER REQUIREMENTS

- Head on the Pump = 309.48 ft
- Water Horsepower = 226.50 HP
- Total Flow = 2,893.26 GPM
- Brake Horsepower = 279.63 HP
- Required Electrical Motor Horsepower = 294.35 HP
**ECONOMIC ANALYSIS**

<table>
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<tr>
<th>INITIAL COST:</th>
<th>TOTAL COST OF SYSTEM = $1551.76</th>
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<tbody>
<tr>
<td><strong>PUMP AND POWER UNIT COST</strong></td>
<td>$15370.76</td>
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<tr>
<td><strong>LATERALS COST</strong></td>
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<td><strong>TOTAL COST OF SYSTEM</strong></td>
<td>$57151.76</td>
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<td><strong>ANNUAL COST:</strong></td>
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<td><strong>ANNUAL FIXED COST</strong></td>
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<tr>
<td><strong>TOTAL ANNUAL COST</strong></td>
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<td><strong>NET ANNUAL INCOME/ACRE</strong></td>
<td>$127.00</td>
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<td><strong>NO. OF YEARS NEEDED TO PAY FOR THE SYSTEM</strong></td>
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<td><strong>ANNUAL MAIN LINE COST</strong></td>
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<td><strong>ANNUAL PUMPING COST</strong></td>
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**MAINLINE COST = $25455.98**

**SPRINKLERS COST = $2630.32**

**COST PER ACRE = $255.71**

**ANNUAL O AND M COST = $15212.36**

**TOTAL ANNUAL COST PER ACRE = $99.00**

**ANNUAL PROFIT/ACRE = $27.20**