Simulating Farm Irrigation System Energy Requirements

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ABSTRACT

The development of the energy crisis has resulted in close monitoring of depletable energy resources in the United States. Within the agricultural sector, irrigation is a large consumer of energy, with the potential of using several times more energy than all other agricultural field operations. A better understanding of how energy is used by different irrigation systems could facilitate more efficient use of energy by one of the largest energy consumers in agriculture.

This study attempts to realistically evaluate the total amount of non-renewable energy resources consumed in the irrigation process. Five portable and permanent sprinkler system types, plus trickle and gravity irrigation systems, were studied. An evaluation of the energy required to manufacture, install, operate, and transport the equipment for an entire irrigation season was included in the analysis. This evaluation was conducted in a variety of operating situations, with varying acreages, consumptive use rates, and total irrigation requirements.

The evaluation of energy consumed by irrigation systems presented in this study was made with the use of a simulation model developed on the Oregon State University OS-3 Computer System. The model predicted energy requirements of an irrigation system by calculating pumping energy from basic hydraulic equations and manufacturing energy from the amounts of basic materials composing the irrigation system. Energy for installation and for field transportation were evaluated by simulating methods of operation and management used in Oregon. Input parameters used in the modeling process closely reproduced operating conditions encountered in Oregon. System types, component depreciation life, irrigation efficiencies and the range of irrigation requirements were ones that could typically be found in Oregon.

For the situations considered, gravity irrigation required substantially less energy than other system types. The energy needed for drip systems was about midway between the energy requirement for gravity and sprinkler systems in most cases considered. The relative order of energy requirements for the various sprinkler systems was dependent upon the prescribed operating conditions.

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I. INTRODUCTION

With the development of the energy crisis, an increasing amount of attention has been focused on the use of our depletable energy resources. When considering measures to conserve these energy resources, operations which are the largest energy consumers are quite naturally expected to contribute the largest energy savings. While agriculture in the United States does not compare with the transportation industry as a user of energy, it is quite energy-intensive. Barnes (1973) estimated that agriculture accounted directly for the use of an equivalent of 250 million barrels of crude oil in 1970. Indirect consumption by agriculture accounted for the equivalent of an additional 250 million barrels of crude oil. When all the energy that goes into food production in the United States is considered, including food processing and preparation, the food cycle consumes about 12 percent of the national energy budget (Hirst, 1974). The extreme dependence of agriculture on energy, especially petroleum products, requires that immediate action be taken to ensure that all energy allocated to agriculture is used economically.

In the western part of the United States, one of the largest single energy consuming agricultural operations is irrigation. Barnes et al. (1973) indicated that over 34 million acres of land are irrigated in the 18 western "irrigation states." This acreage (within the states of Washington, Oregon, California, Idaho, Nevada, Utah, Arizona, Montana, Wyoming, Colorado, New Mexico, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Texas, and Louisiana) comprises approximately ten percent of the crop land in the United States. On much of this acreage, 50 to 100 percent of the crop production is dependent upon proper application of irrigation water. A study in California (Williams and Chancellor, 1974) found that for nine crop types grown extensively in that state, the application of irrigation water was by far the largest single factor affecting crop production. It was estimated that a 50 percent reduction in the amount of irrigation water applied would result in an average yield reduction of 49 percent for the nine crop types considered, and a reduction in crop value of over $1 billion.

Considering no yield, or a greatly reduced yield, as alternatives, the price of irrigation appears cheap, whatever the cost in dollars and energy. Despite the vital nature of its products, agriculture must not assume that it will always have sufficient energy available to constantly increase its output, or even to continue at present operating levels. If energy becomes a limiting constraint upon agricultural production, the first areas to be removed from production as a conservation measure would probably be marginal acreages irrigated at extremely high energy costs. One study (Barnes et al., 1973) estimated that in some cases the energy required for pumping irrigation water can be as much as 20 times the energy required for all other field operations in producing a crop. Another study in California (Cervinka et al., 1974) estimated that the pumping of irrigation water consumed 13.2 percent of the total energy requirement for agriculture in that state.

The vital dependence of crop production upon irrigation water in many of the western states, and the equally vital dependence of irrigation upon the available energy supplies, makes it extremely important to understand the energy requirements of the irrigation process. An understanding of energy consumption in irrigation could make it possible to reduce the losses in existing irrigation systems, and the ability to predict energy requirements of new irrigation systems would promote the most efficient designs. Recognizing the sizable variations in operating conditions and procedures in differing locations, and the many different options available to an irrigator, this study will attempt to evaluate and quantify two total energy requirements of typical farm irrigation systems in the state of Oregon.

According to recent estimates (Shearer, 1975), there are approximately 1,938,000 acres of irrigated crop land in Oregon. Gravity irrigation is the predominant type, covering 1,120,000 acres. Hand move sprinkler systems are the second most popular type, irrigating 500,000 acres, while side roll sprinkler systems account for 175,000 acres, center pivot sprinkler systems for 110,000 acres, solid set sprinkler systems for 20,000 acres, big gun sprinkler systems for 12,000 acres, and trickle irrigation systems for 1,000 acres. In many areas of the state the water source is surface water, developed by government-financed irrigation projects. When ground water is the source, or when the surface water supply lies below the land to be irrigated, more than 99 percent of the pumping plants used to lift irrigation water are powered by electric motors.

The state of Oregon has a broad range of agricultural crops grown under equally varied climatic conditions. The Oregon irrigator can consider several types of systems to satisfy his irrigation needs, with a wide variety of commercial equipment available within each system type. The situation could range from a center pivot sprinkler system irrigating a quarter section of potatoes in the Columbia Basin with a seasonal irrigation requirement of 24 inches of water and a peak consumptive use rate of three quarters of an inch every two days, to twenty acres of peppermint in the Willamette Valley irrigated with a hand move sprinkler system requiring only ten inches of water seasonally and having a peak demand of one and one-half inches every ten days.

To provide estimates of the energy needs of a number of different systems in a wide variety of operating conditions, a computer model has been developed which simulates the required energy inputs to irrigation systems. The model can simulate hand move, side roll, center pivot, solid set, and permanent sprinkler systems, as well as drip irrigation systems and furrow and corrugation surface irrigation systems. To simulate the irrigation of different crops in differing consumptive use situations, several input parameters can be varied to determine their effects on the ultimate energy requirement of the system under consideration.

Previous studies of irrigation energy requirements have generally included only the energy required to pump water. This study considers not only pumping energy, but also includes the energy required to manufacture irrigation equipment, to prepare the land to accept an irrigation system, and to install the system in the field. In this way an estimate of the total system energy requirement can be evaluated, and comparisons of systems can determine relative energy efficiencies.

II. REVIEW OF LITERATURE

Since the development of the energy shortage, many studies addressing energy consumption have been conducted. Agricultural use of energy has been investigated, though most studies have been general views of the total industry. A few, however, have considered individual areas within agriculture to determine the energy use patterns of specific operations.

A study by the California Department of Food and Agriculture and the University of California, Davis (Cervinka et al., 1974) recently evaluated the use of energy by agriculture in that state. The consumption of energy was partitioned into several different categories, one of which was irrigation. Of the nearly 36 million acres of farmland in California, 7,240,131 acres are irrigated. A total of 20,836,379 acre-feet of water was applied to these lands in 1969 (Census, 1969) at a rate of 2.88 acre-feet per acre. For the irrigation water pumped, census figures show that 7,223,133,831 kilowatt-hours of electricity were used in pumping. Nonelectric-powered pumping plants supplied the balance of the pumping energy, using an estimated 6,530,000 gallons of diesel fuel, 487,000 gallons of gasoline, 3,700,000 gallons of L.P. gas, and 1,140,000,000 cubic feet of natural gas. Assuming an efficiency of 0.30 for the generation of electricity in a coal-fired plant, an equivalent of 8.67×10^{13} kilo-joules of fossil fuel were consumed by electric powered irrigation pumping plants. Using the heating value of fuels listed in the C.R.C. Handbook of Chemistry and Physics, nonelectric pumping plants consumed another 2.68×10^{12} kilo-joules of fuel energy, for a total annual consumption of 8.93×10^{13} kilo-joules for pumping irrigation water in California. Though the report did not indicate the number of acres irrigated with pumped water, the average energy consumption for the entire state would be 12,340,779 kilo-joules per acre irrigated, and 4,284,993 kilo-joules per acre-foot of water applied.[1] It should be emphasized that these values only consider pumping energy, and exclude the energy required to manufacture equipment, bury pipe or level fields.

A more comprehensive study of energy use in irrigation was conducted by Utah State University (Batty et al., 1974). The approach was to calculate energy inputs required to irrigate a given block of land with the various options in irrigation system types available in the area. The study included the total energy inputs necessary to manufacture and install the required equipment, to pump the water, to prepare the land by leveling and to meet any labor requirements, in order to satisfy a net irrigation requirement of 36 inches on a 160-acre field. Systems analyzed were ordinary surface irrigation, surface irrigation with a runoff recovery system, solid set sprinkler, permanent sprinkler, hand move sprinkler, side roll sprinkler, center pivot sprinkler, travelling big gun sprinkler and trickle irrigation. The study considered the application efficiency of each system type, the energy to manufacture materials used in system components, the expected operating life of each of the system components, the labor required to operate each system throughout the season and the energy necessary to install each system in working order in the field. Results were expressed as energy required per season of operation. One-time-only energy expenditures, such as equipment manufacture, were prorated over the expected operating life of the components. Energy for land leveling was prorated over the number of years the system could be expected to operate without releveling or changing to another system type. In this case, a system life of 20 years was used. Seasonal requirements such as pumping energy and labor

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[1]The last two figures were calculated by these authors.

were totaled directly. Human labor was rated at 300 kilo-calories per man-hour. The total energy was then calculated for each acre irrigated for one season.

The estimates of total seasonal energy inputs required, in kilo-calories per acre, were (in order of increasing inputs): surface irrigation without runoff recovery, 197,000 kcal. per acre; surface irrigation with runoff recovery, 290,000 kcal. per acre; hand move sprinklers, 968,500 kcal. per acre; trickle irrigation, 998,600 kcal. per acre; side roll sprinklers, 1,007,100 kcal. per acre; center pivot sprinklers, 1,252,600 kcal. per acre; solid set sprinklers, 1,384,000 kcal. per acre; travelling big gun sprinkler, 1,858,000 kcal. per acre. These energy consumption figures were calculated with the assumption that water was available at the edge of the field at ground level. The systems for which the energy consumption was calculated were designed to meet a peak daily net irrigation requirement of 0.33 inch per day.

Batty et al., (1974) concluded that the installation energy consumed a significant portion of the total energy requirements of each irrigation system. For the example considered in the study, surface irrigation was the most energy conservative. However, this conclusion was prefaced by the statement that other systems considered were more water-conservative. In a situation where delivering high quality irrigation water in adequate amounts had an extremely high energy cost, such as desalinized water, systems with a higher irrigation efficiency might possibly have a lower total energy requirement.

An earlier study conducted by Washington State University (Doran and Holland, 1967) evaluated the cost of owning and operating side roll, hand move, and center pivot sprinkler systems in the Columbia Basin of Washington. Since this was an economic study, its results do not apply directly to a study of energy requirements, but some interesting relationships came to light. Hand move and side roll sprinkler systems with sprinkler spacings of 40 feet by 50 feet were found to have the lowest cost for electric pumping energy. The same systems with sprinkler spacings of 40 feet by 60 feet, and center pivot sprinkler systems all had approximately a 25 percent higher pumping cost. However, when total annual costs, including labor, maintenance, transport, and overhead were considered, the center pivot systems had the lowest annual cost for the range of conditions studied. The systems were designed to supply 42 acre-inches of water per acre during the season at a maximum daily rate of 0.35 acre-inches per acre. A cost evaluation showed that labor costs were the major reason for the hand move and side roll systems' greater annual expenses.

III. MODEL DEVELOPMENT

The first step in the actual calculation of the energy consumption of an irrigation system was the development of a working computer model to simulate the operation of a particular system. Since the aim of the model was not to actually design an irrigation system, but rather to compute system energy needs, the model was implemented on the OS-3 conversational time sharing computer system. OS-3 permitted the modeller to communicate instantaneously with the model, making design changes whenever model output indicated an alteration was necessary. The model was conversational in nature, asking certain questions about the irrigation system design and feeding back preliminary answers, allowing the modeller to make further decisions so that the final design required a minimum of energy inputs.

To simplify the calculation procedure, the energy consuming features of irrigation systems were divided into four basic areas:

1. Operating Energy,
2. Manufacturing Energy,
3. Transportation Energy, and
4. Installation Energy.

One particular section of the model was devoted to quantifying the energy consumed by each of these portions of an irrigation system.

Only the consumption of nonrenewable energy, specifically fossil fuel sources, was considered by this model. When reference was made to energy used by a system, the actual energy was that required to be developed by the combustion of a basic fuel source, such as coal, diesel fuel, or natural gas, etc., to produce the final product. For this reason, the efficiencies of electric power generation were also included. However, human energy was <u>not</u> taken into consideration in this model. The justification for this omission was that human energy input into irrigation is relatively small, if the power developed by a man working is the quantity included. Israelson and Hansen (1962) rated the output of an average man at one horsepower-hour per eight-hour day. However, if the fuel energy required to produce the food the man must eat to develop that energy level were considered, human energy would probably be the largest and, by far, the most inefficient point of energy use in irrigation or any other process.

To determine the calculations necessary in the model, the form of the input data must be known. Acreage to be irrigated is one of the first basic inputs. Total amount of water to be applied and rate of application must be known. At this point the model operator must make some design decisions, using his knowledge of the situation, to transform the available data into inputs which the computer can use. Knowing the crop, the climate in which it is growing, and the type of irrigation system most compatible with land slope and soil water intake rate, the operator can provide values for the net irrigation requirement, the peak consumptive use and the irrigation efficiency. Then, by specifying the configuration of the system and the size of individual components, the operator has provided the model all necessary information to calculate the energy for each basic segment, and for the total system.

Once system configuration and components are supplied, the model must have certain basic data to perform necessary calculations. To determine the energy to manufacture components, the model must know the type and amount of material used for each component, and the energy to make that material. The dimensions of pipeline components are industry standards and vary only nominally from one manufacturer to another. However, sprinklers vary considerably throughout the industry;

for simplification, Rain Bird Model 30 sprinklers were considered to be used on hand move and side roll systems, and Rain Bird Model 20 for solid set and permanent systems. A further simplification was made by assuming the sprinklers were entirely made of brass. The dimensions of mainlines, laterals, wheel lines, couplers, sprinklers, and riser pipes are listed in Table 1. The energy to make pipe and sprinkler components which are composed of homogeneous materials can be easily evaluated if the energy of manufacture per unit weight of material is known. Data on manufacturing energy were obtained from several sources and were found to vary considerably from source to source. The values of manufacturing energy of several sources are listed in Table 2, along with the values used in this study. The values eventually used for this paper were not necessarily averages of the available data, but the available data were used as a guide in choosing the final manufacturing energy for each material type.

The energy values listed in Table 2 are the quantities of energy in the form of basic fossil fuel required to produce one pound of the listed materials. Whenever electricity was the major form of energy used, such as in the electrolysis of aluminum, an efficiency of 0.30 was assumed for the generation of electricity from coal. This efficiency was based on a generation efficiency for industry of 0.328 published by Berry and Makino (1974), and an efficiency of 0.32 published by a congressional subcommittee (U.S. Senate, 1974). The source for the congressional figure was Consolidated Edison, which suggested an average transmission loss of nine percent be incorporated, yielding a total efficiency from generator to source of utilization of approximately 0.30.

The computer model is a collection of several different subprograms, each group of which was created to simulate one particular type of irrigation system. The subprograms exist in three different levels, consisting of a main program in Level I which directs the operation of the total model, the Level II subroutines which accumulate and print the final answers of each segment of an irrigation system, the values of which are calculated in the subroutines in Level III. After completing the analysis of one irrigation system, the main program can initiate the analysis of another system, or terminate the model as designated by the operator. Figure 1 illustrates the movement of information between subprograms of the model.

To further illustrate how the model functions, an explanation of the steps followed in analyzing a hand move sprinkler system will be presented. The hand move system was chosen for this explanation because it was the first system modeled and the subprograms for it were prototypes for the modeling of subsequent systems.

When the operator initiates communication with the model, he is immediately interfaced with the main program, called IRRIGATE (Level I), via a teletype terminal. To simplify the input process the program is conversational, allowing the model to respond with a numbered list of the irrigation systems it is capable of analyzing. The operator replies with the number of the system he wishes to consider. For example, the number 1 directed the data input by calling subroutine STEPMAIN (Level II) to perform the next functions. The major functions of STEPMAIN are to read the input data and to write out the results of the analysis. In this case, the known inputs were placed in a data file and read as soon as STEPMAIN began functioning. After the data file is read, the subroutine OPRATE 1 (Level III) is called to calculate the operating energy of the system as defined on the data file.

The first step performed in OPRATE 1 is to calculate the length of the lateral lines (TLNLT). The model assumes that the mainline pipe runs down the center of the field, parallel to the longest dimension of the field. Therefore, the length of the lateral lines is equal to half the field width (WIDE) specified in the input data. The sprinkler spacing on the lateral (XLNLT) is specified in the input

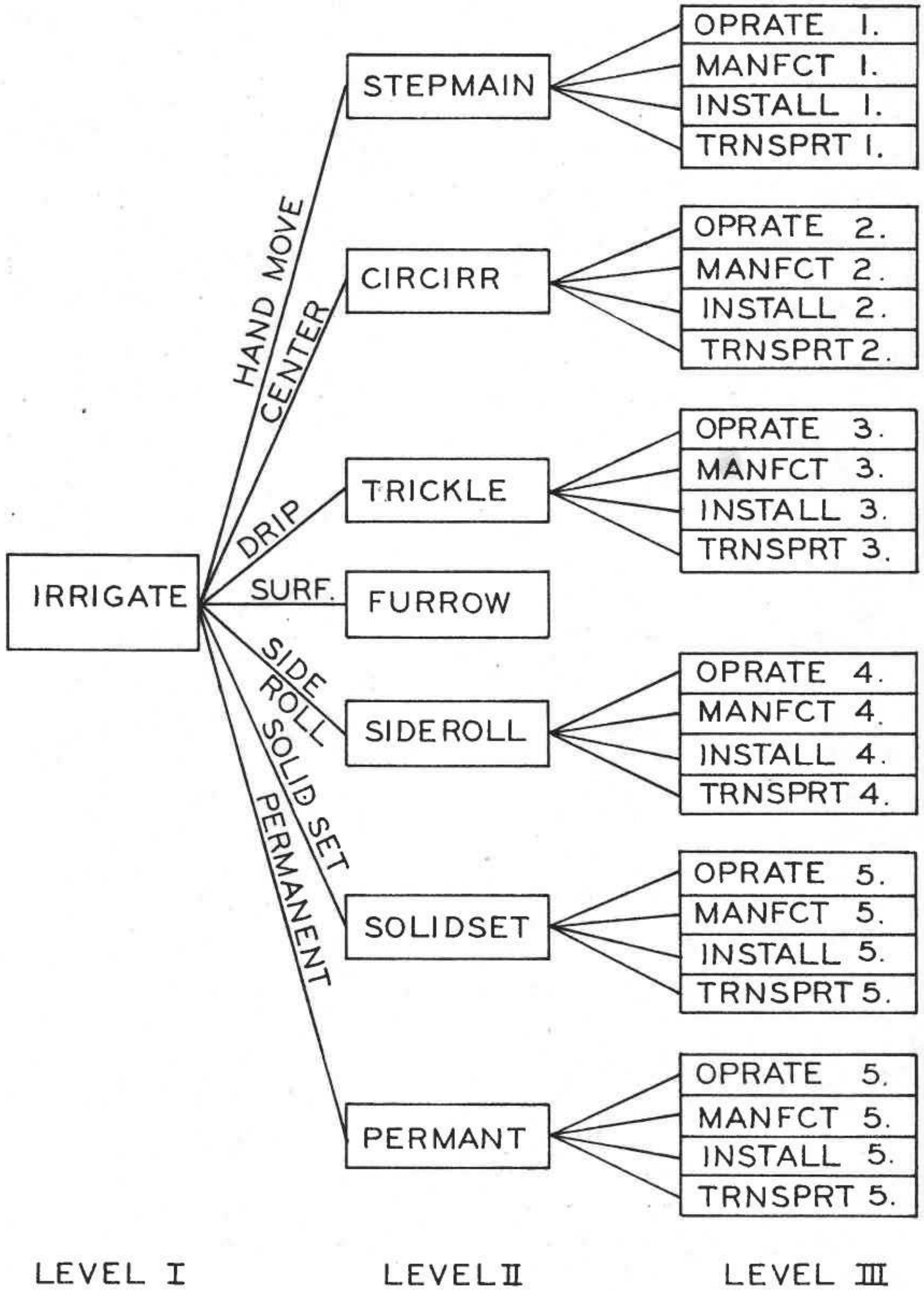

Figure 1. Schematic diagram of paths of information transfer in the computer model.

data, and the quotient of the total lateral length and the sprinkler spacing yields the number of sprinklers per lateral (NOSPR). The basic system pumping capacity is determined by the equation,

QPUMP = (ACRE*DNA*453.)/(FREQ*HPD*EFIR)

as listed by Pair (1969), where,

QPUMP = system pumping capacity, (gal./min.)
ACRE = acreage to be irrigated, (acres)
DNA = net irrigation requirement, (in./application)
FREQ = application frequency, (days/application)
HPD = daily operation time, (hr./day)
EFIR = irrigation efficiency
453. = conversion factor from (acre-in./hr.) to (gal./min.)

All required information for the equation is given in the input data file. The pumping rate is printed out, and the model pauses to allow the operator to exercise his judgment as to how many laterals there will be in the system. When the number of laterals (XNLTS) is entered, it is divided into the pumping rate to find the flow rate in each lateral (QLT). The flow rate in each lateral is printed, and the operator can now input the size of the lateral pipe line (IDLT) that will carry this flow. Another data input entered at this time is the number of "steps" in the mainline (NMS). A step is a continuous section of pipe with a constant diameter and a constant flow rate. The number of steps in the mainline network will be dependent upon the number of laterals and the manner in which the laterals are arranged. The model will now ask for the values of the diameter [IDM(I)], flow rate [QM(I)], and length [XLM(I)] of each mainline step. All steps must be included; however, only the flow rates in the steps leading to the lateral which will result in the maximum total dynamic head should be entered. The flow rates for all other steps not on this critical path should be entered as having zero flow.

All input data necessary to calculate the operating energy are now stored in the model. A check on whether the system is feasible is provided by dividing the lateral flow rate by the number of sprinklers on the lateral to obtain the sprinkler discharge (QSPR). The size of the nozzle needed to provide this discharge is obtained using a form of the orifice equation (Sabersky, 1971),

$$DNOZ = \left[QSPR/(28.94*SPOH^{.5})\right]^{.5}$$

where:

QSPR = sprinkler discharge (gal./min.)

DNOZ = nozzle diameter (in.)

SPOH = sprinkler outlet pressure (lb. in.$^{-2}$)

28.94 = conversion factor accounting for units and nozzle coefficient of 0.9711 for Rain Bird 30-W nozzles (gal.^{2} min.$^{-2}$ in.$^{-1}$ lb.$^{-.5}$)

with the sprinkler outlet pressure as a specified input. If the sprinkler cannot possibly operate with an acceptable coefficient of uniformity, and thereby hope to achieve the irrigation efficiency initially specified, the spacing and pressure of the sprinklers and the number of laterals in the system can be altered until a suitable level of performance is achieved.

The number of irrigation cycles per season (NIPS) is calculated by dividing the total seasonal application (TNA) by the application per irrigation (DNA). The total operating time per season (TTOT) is the product of the number of cycles, the frequency of irrigation (FREQ) and the hours of operation per day (HPD). In order to predict the energy required to operate the pump for this length of time, the total dynamic head of the system must be calculated. To calculate the friction component of the total dynamic head, the friction loss in each segment of the mainline and the lateral leading to the critical sprinkler must be calculated.

To calculate the friction losses of the mainline, a form of the Hazen-Williams equation (Morris and Wiggert, 1972) was used as follows:

$$HFP = \left[\frac{QMF*[XLM(I)]^{.54}}{1.318*CHWM*\pi*DMF^2*\left(\frac{DMF}{4}\right)^{.63}} \right]^{1.85}$$

where:

HFP = friction head loss in the pipe segment, (ft.)
XLM(I) = length of pipe segment, I, (ft.)
DMF = diameter of pipe segment, I, (ft.)
QMF = flow rate in pipe segment, I, ($ft.^3/sec.$)
CHWM = Hazen-Williams coefficient

This equation is executed a specified number of times, with the value of the subscript, (I), increasing from one to the total number of mainline steps (NMS) in the system, and the total head loss for the entire mainline (HFM) is accumulated. The head loss for the lateral line is calculated using a similar form of the Hazen-Williams equation, with the additional parameter of Christiansen's F factor to account for the manifold flow in the line. The equation for the F factor (Pair, 1969) is:

$$F = \frac{1}{(M + 1)} + \frac{1}{2N} + \frac{(M - 1)^{.5}}{6N^2}$$

where:

M = exponent of the velocity term in the head loss equation (1.85 for Hazen-Williams)
N = number of outlets on the line (NOSPR)

The total dynamic head (TDH) is found by totaling the calculated mainline friction head loss (HFM), the calculated lateral friction head loss (HFL), plus the specified input values of sprinkler operating head (SPOHF), pump suction lift (STL), elevation difference from pump to field (ELEVDF), friction loss in the suction line (HFSL), and height of the riser pipe (RIHT), all expressed in units of feet.

The power required to pump the water is given by the equation (Pair et al., 1969),

$$WHP = \frac{TDH*QPUMP}{3960}$$

where:

WHP = water horsepower, (hp.)
TDH = total dynamic head, (ft.)
QPUMP = pump discharge, (gal./min.)
3960 = conversion factor, (ft.-gal./min.-hp.)

To determine the brake horsepower of the motor required to drive the pump (BHP), the water horsepower must be divided by the efficiency of the pump (EFPP). If an internal combustion engine is the power source, dividing the brake horsepower by the engine efficiency (EFMO) will yield the horsepower potential in fuel (THHP) required for pumping. If an electric motor is the power source, then brake horsepower must be divided by both motor efficiency and efficiency of the electric generating plant (EFGP) to determine the potential horsepower in fossil fuel required. The total energy required for pumping during the season (TENPS) is simply the product of fuel horsepower and total operating time.

After printing values for head losses and pumping energy, subroutine OPRATE 1 (Level III) returns control to STEPMAIN (Level II). Calculation proceeds with the calling of the next subroutine, MANFCT1 (Level III), in which the energy to manufacture system components is estimated.

MANFCT1 first calculates the energy to manufacture the mainline network. The information on each of the mainline segments is transferred from the STEPMAIN subroutine, and dimensional data about standard pipes of various materials and sizes are retrieved from a data file (*MAINLNS). The size of each pipe sigment is matched with the proper size in the data file. An indicator variable (MMTY) defined in the input data is checked to determine the mainline material type. For example, MMTY = 2 would indicate aluminum mainlines, appropriate for a hand move system. With the weight per foot of tubing, the weight of each coupler, and length of each individual pipe section composing that segment of the mainline, the weight of each mainline segment is calculated (TMNWT). Multiplying this weight by the manufacturing energy per pound for the appropriate material type yields the energy to manufacture that segment (EMMFT). Repeating the process for each segment in the network will yield the total energy of manufacture for the mainlines (TEMMFT).

A procedure similar to that used on the mainlines is then conducted for the energy to manufacture laterals (ELMFT). The energy for manufacturing sprinklers (ENSPMFT) is calculated, using the assumption that all sprinklers weigh 1.1 pounds (the weight of a Rain Bird Model 30) and are entirely made of brass. The energy to manufacture the pumping plant is calculated by assuming the plant horsepower rating is the next standard size equal to or larger than the brake horsepower requirement for the pump. This unit size [PUMPHP(I)] is chosen from a list of available motor sizes and is multiplied by a manufacturing energy per unit horsepower figure to yield the energy to manufacture the pumping plant (EPPMFT).

After printing the values of the manufacturing energy for the mainlines, laterals, sprinklers, and pumping plant, and the size of the pumping plant, control is returned to STEPMAIN (Level II). The next operation, to calculate the transport energy for the system, is performed in the subroutine TRNSPRT (Level III), which is called by STEPMAIN (Level II).

Transport energy is divided into two areas, manufacturing energy for the pipe trailer, and fuel for the tractor to pull the trailer. The trailer is assumed to be made of steel and to weigh an amount specified in the input data (TRWT). The energy to manufacture the trailer (ETRMFT) is calculated according to a process similar to those described above. The trailer is needed to move two laterals the length of the field once during each irrigation cycle, requiring two hours at three gallons of diesel fuel per hour. The trailer manufacturing energy is prorated over the trailer's operating life (assumed to be 20 years), so that the total transport energy per season (ETTRP) can be given as a single figure (by summing trailer manufacturing energy and fuel necessary to pull the trailer). Tractor manufacturing energy is not included, as the amount expended in moving irrigation pipes is assumed to be of negligible magnitude when compared to its other primary jobs.

When the transport energy is printed, control is again returned to subroutine STEPMAIN (Level II), which calls subroutine INSTALL1, to calculate installation energy. For a hand move system, installation energy is assumed to be negligible unless some of the pipelines are buried. The operator has the option of specifying burial of pipes. If pipes are buried, they are assumed to be in a trench requiring approximately one quarter of a gallon of diesel fuel per cubic yard to excavate and back fill. Pipes are assumed to have two feet of cover over them, and to require a width of four inches greater than their nominal width. The product of the total volume of excavated trench and energy per unit volume yields the total installation energy.

After the installation energy is printed, control returns to STEPMAIN (Level II). The total energy for seasonal operation (TOTSEN) is calculated by summing the following:

1. Total seasonal pumping energy (TENPS)
2. Total seasonal transport energy (ETTRP)

3. Energy to manufacture mainlines (EMMFT), laterals (ELMFT), and installation energy (ENINST), all prorated over their expected life (20 years)
4. Energy to manufacture pumping plant (ENPPMFT), prorated over its expected life (15 years)
5. Energy to manufacture sprinklers (ENSPMFT), prorated over their expected life (10 years).

Dividing total seasonal energy by number of irrigated acres yields seasonal energy per acre (SENPA). Seasonal energy per acre is divided by total seasonal application (TNA) to yield seasonal energy per acre-inch (ENPAI).

After all energy totals are printed by STEPMAIN (Level II), control returns to the main program, IRRIGATE (Level I). The operator may then consider another system or terminate the execution of the model.

All other systems are modeled in a similar fashion, with a few alterations to allow for basic differences between system types. For example, when a center pivot system is being modeled, the first subroutine called is CIRCIRR (Level II). In this system, the mainline is assumed to be of constant size, and to run to the center of a square field. The lateral is seven inches in diameter; with its support towers, it is assumed to weigh 35,000 pounds, for a system used in a 160-acre field. The lateral and towers are assumed to be made entirely of steel. The lateral for a 160-acre field is 1280 feet long, with ten support towers, each powered by a one horsepower electric motor. Tower motors are assumed to operate at three quarters of their rated capacity, and their power consumption is calculated accordingly. Sprinklers on the lateral are spaced at non-constant intervals to allow for uniform application. There are no big gun sprinklers for irrigating corners, and the system is assumed to irrigate 125 acres in a 160-acre field. Lateral hydraulics are simulated using the Hazen-Williams friction head loss equation, with a manifold flow factor for variably-spaced outlets of 0.543, as measured by Shu and Moe (1972).

The subroutine SOLIDSET (Level II) is called by the main program when a solid set irrigation system is being simulated. One difference between this system and the hand move system is that there are enough laterals to cover the entire field, but only a portion of them operate at any one time. The segment of the mainline where laterals are in operation must be considered as a manifold flow situation. Transport energy includes only that required to lay out and pick up the pipe network at the beginning and end of each irrigation season.

When a side roll sprinkler system is being modeled, subroutine SIDEMOVE (Level II) is called by the main program. The group of subroutines controlled by SIDEMOVE functions almost exactly as that which models a hand move system. One of the notable exceptions is that only four and five inch diameter laterals are considered. The lateral walls are of heavier gauge material than standard laterals, and each section has a wheel as an integral part. Movement of laterals in the field is different, in that a pair of laterals, one on either side of the mainline, moves as a single unit. Each of these pairs of laterals is propelled by a moving device powered by a four horsepower engine. The moving unit is assumed to require 10,000 kilowatt-hours of energy to manufacture, and to consume one half gallon of diesel fuel per hour of operation. It is further assumed that 15 minutes of operation per pair of laterals per move are required for transport.

The subroutine TRICKLE (Level II) is called by the main program when a drip irrigation system is being simulated. This system is simulated in much the same manner as the solid set system. The major differences are that all laterals operate at once, and that the system is a permanent installation with buried pipelines and no required transportation energy. The operator may choose either a micro-tube type emitter or an emitter with a spiral restricting path, which are two of the more widely used emitters in Oregon.

For modeling a permanent type sprinkler system, the subroutine SOLIDSET (Level II) is again called by the main program. When SOLIDSET is called through the permanent sprinkler system branch, a "flag" is set which eliminates the TRNSPRTS subroutine (Level III) since no transport energy is required. Installation energy is calculated for both buried lateral and mainline pipes. With these exceptions, the subroutines function exactly the same as when modeling a solid set sprinkler system.

For the simulation of a surface irrigation system, the subroutine FURROW (Level II) is called by the main program. This subroutine first calculates the energy required to level the field, where required yardage per acre and average length of haul for leveling equipment are inputs. The operator has the option of selecting one of three leveling units (125 horsepower crawler with a 10 cubic yard carry-all, 200 horsepower crawler with a 14 cubic yard carry-all, 300 horsepower crawler with a 20 cubic yard carry-all). The average hauling rates are estimated using data published by Caterpillar Tractor Company (1955a). After determining total time required for field leveling, the energy required to perform the operation is calculated using fuel and lubricant consumption estimates made by Caterpillar Tractor Company (1955b). After calculating leveling energy, the energy to make the distribution network in the field is estimated. Two types of networks are considered, furrows with a three foot spacing and corrugations with a 20-inch spacing. The estimates of the energy required per acre to form furrows and corrugations were provided by local farm operators (Namba and Teramura, 1975). In estimating the energy required to make the field head ditch, three types of structures are considered. The available options are an unlined earthen ditch, a concrete lined ditch, or a gated aluminum pipe. The earthen ditch is assumed to require a minimal amount of energy, rated at one hundredth of a kilowatt-hour per lineal foot of ditch. The concrete lined ditch is assumed to have a trapezoidal cross section with a lining two inches thick. The gated pipe is assumed to require approximately the same energy as aluminum mainlines of equal size, as defined in the hand move sprinkler system model. When an open head ditch is considered, devices for releasing water onto the field from the ditch can be siphon tubes, or either earthen or concrete turnouts. The siphon tubes are assumed to be aluminum, four feet long and one inch in diameter, requiring about ten kilowatt-hours per tube to manufacture. Earthen turnouts are assumed to require a negligible amount of energy, since human energy (shoveling) is the major input. Concrete turnout devices, such as gated spiles, were assumed to require 126 kilowatt-hours per structure to manufacture. It is assumed that one siphon tube is used for each furrow or corrugation, but each turnout or spile is assumed to supply water for three furrows or corrugations. The operator also has the option of using a water source that cannot be applied to the field by gravity flow. In this case, the pumping energy to apply the necessary amount of water at any specified static lift was calculated. When a gated pipe is used, the friction loss in the pipe is included.

The total of all calculated energy requirements per acre irrigated and per acre-inch of water applied is printed. Control of the model functioning is then returned to the main program. For all systems considered, the water is assumed to be available at the edge of the field, and any energy expenditure for main canals or pipelines to deliver water to that point is not included.

IV. MODEL INPUTS

The completion of this computer model has created a tool capable of simulating the total energy consumption for several types of irrigation systems. The inputs necessary for the model to function are fairly simple and should be available to anyone considering installation of an irrigation system. The area and dimensions of the field to be irrigated must be known. This model considers only fields of simple rectangular shape. The total amount of water to be applied, the maximum rate of application, and the frequency of irrigation required to meet peak consumptive use requirements are functions of both crop and climate. Any remaining inputs are basic information about the system type. Dimensions, type of material, and friction coefficients of pipelines must be known. Spacing and operating pressure of sprinklers are data the system designer can easily provide. Static pumping lift, minor friction losses through fittings, and pumping efficiency can be estimated or measured.

For the purpose of this study, the model used input values that approximate irrigation systems generally used in Oregon today. The efficiency of irrigation for each type of system was approximated assuming that each was operated with good management practices. Surface systems were rated at an efficiency of application of 50 percent, while drip systems were rated as 90 percent efficient. Center pivot sprinkler systems were assumed 75 percent efficient, and all other sprinkler systems were rated at 70 percent efficiency.

Pumping units were assumed electrically powered, since the vast majority of pumping units in Oregon are powered by electric motors. Motors were assumed to have a conversion efficiency of 88 percent and pumps were rated as 70 percent efficient; this yields an over all pump and motor unit efficiency of approximately 62 percent. As was the case with manufacturing energy, a generation efficiency of 30 percent was assumed for coal-fired generating plants. Although electricity in Oregon is primarily generated hydroelectrically, this assumption is justified by the knowledge that any power not consumed in Oregon can be transmitted to areas where fossil fuel is the major power source for electric generation.

The configuration of individual systems and the practices used in modeling them were intended to reproduce situations that typically exist in Oregon's irrigated agriculture. The systems modeled were designed to meet net irrigation requirements of 10, 20, and 30 inches of water per season. The different applications can be thought of as representing crops with short, medium, and long growing seasons, respectively. They were further designed to meet consumptive use conditions of 0.1, 0.2, and 0.3 inches per day. The amount of available moisture to be replaced at each irrigation was assumed to be 1.8 inches. This is equivalent to maintaining 50 percent available soil moisture for a plant with a rooting depth of two to two and one half feet in a medium textured soil. This would require the irrigation frequencies of the three consumptive use conditions (0.1, 0.2, and 0.3 in./day) to be 18, 12, and 6 days, respectively, and would be representative of a grain crop growing in a cool humid climate, a moderate climate, and a high desert climate, respectively.

The characteristics of each individual system will be enumerated so that the results of the simulation can be judged accordingly. The hand move sprinkler system, as defined for this study, had a sprinkler spacing of 30 feet by 50 feet, one foot long riser pipes, 40 pounds per square inch average sprinkler pressure, aluminum mainlines and laterals, and was operated 22 hours out of every 24 hours. The side roll sprinkler system had a sprinkler spacing of 40 feet by 60 feet, one half foot long riser pipes, 40 pounds per square inch average sprinkler pressure, aluminum mainlines and laterals, and was operated 22 hours per day. The solid set sprinkler system had a sprinkler spacing of 30 feet by 50 feet, one foot long riser pipes, 40 pounds per square inch average sprinkler pressure, aluminum mainlines and laterals, and was operated 24 hours daily. The permanent sprinkler system had a sprinkler spacing of 30 feet by 50 feet, 14-foot long riser pipes, polyvinylchloride mainlines and laterals, a 40 pounds per square inch sprinkler pressure, and was operated 24 hours daily. The center pivot sprinkler system had variable sprinkler spacing, no riser pipes, ten towers powered by electric motors, 125-foot spans between towers, 12-foot pipe clearance, polyvinylchloride mainlines and a steel lateral, 60 pounds per square inch end sprinkler pressure, and could operate automatically for a maximum of 144 hours continuously. The drip irrigation system had an orchard plant spacing of 25 feet by 25 feet, multiple polyethylene micro-tube emitters, polyvinylchloride mainlines and laterals, an emitter pressure of 15 pounds per square inch, and operated 18 hours per day. The surface irrigation system was the corrugation type, using aluminum siphon tubes with an unlined earthen head ditch. Field leveling was done by a 200 horsepower crawler, with a 14 cubic yard carry-all, moving 400 cubic yards of soil per acre, with an average haul distance of 600 feet.

Water was available at the edge of the field at ground level for all the systems. Therefore, there was no pumping required for the surface system, and no static pumping lift required for the pressurized systems. All pressurized systems had a ten foot miscellaneous friction head loss included in the total dynamic head to account for losses in special fittings, such as pump adapters and valve-opening elbows.

V. MODEL OUTPUT AND INTERPRETATION

The results of the model simulation with input data listed in the previous section are presented graphically in a group of charts in this section. The data are presented in three different ways. First, the relationships between irrigation system energy requirement and consumptive use rate on a given acreage, for a selected seasonal application, are presented in Figures 2-10. Next, the relationships between system energy requirement and total seasonal application on a given acreage, for selected consumptive use rates, are presented in Figures 11-19. Finally, the relationships between system energy requirement and acreage irrigated for a given seasonal application, at a selected consumptive use rate, are presented in Figures 20-28. The center pivot system was considered on only 160-acre fields. All other types of systems were considered on 20-, 80-, and 160-acre fields.

Several points become immediately evident from the data. First of all, surface irrigation consistently requires the least energy in all cases. Second, drip irrigation, while requiring approximately five to ten times the energy required by surface irrigation in the cases considered, was always the second lowest user of energy. There is a substantial jump in required energy between the drip system and the remaining systems, and the order in which these follow is not constant.

The acreage irrigated and the amount and rate of application appeared to have a considerable effect on the energy requirement of some systems. Some of these effects appeared valid for the systems concerned, while others could be attributed to short-comings in the model.

Considering Figures 20-28, the hand move system would be expected to exhibit behavior similar to the side roll system. In fact, the hand move system would be expected to require a

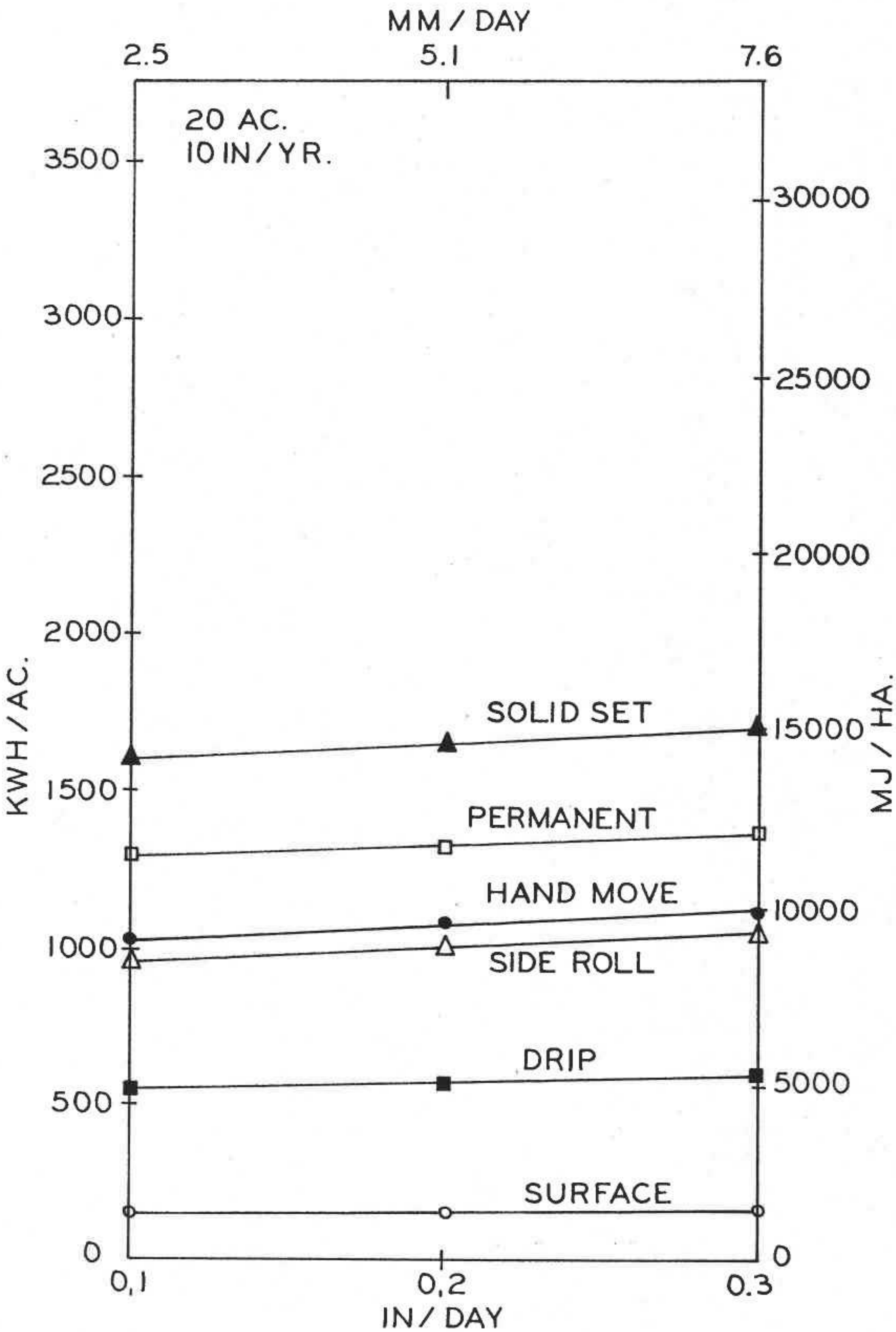

Figure 2. Plot of total seasonal energy as a function of consumptive use rate for a 10 inch (254 mm) seasonal application on a 20 acre (8.1 ha.) field.

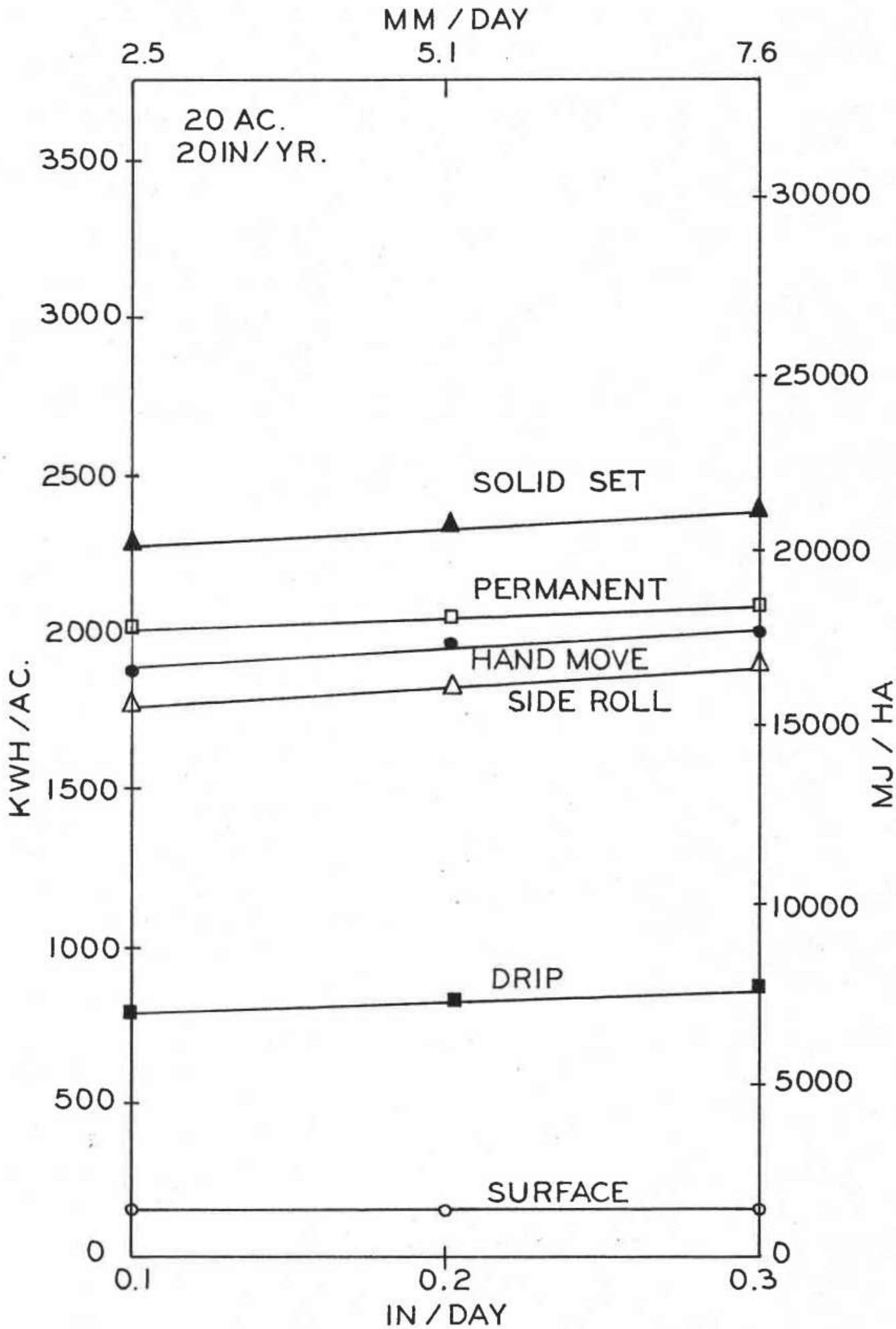

Figure 3. Plot of total seasonal energy as a function of consumptive use rate for a 20 inch (508 mm) seasonal application on a 20 acre (8.1 ha.) field.

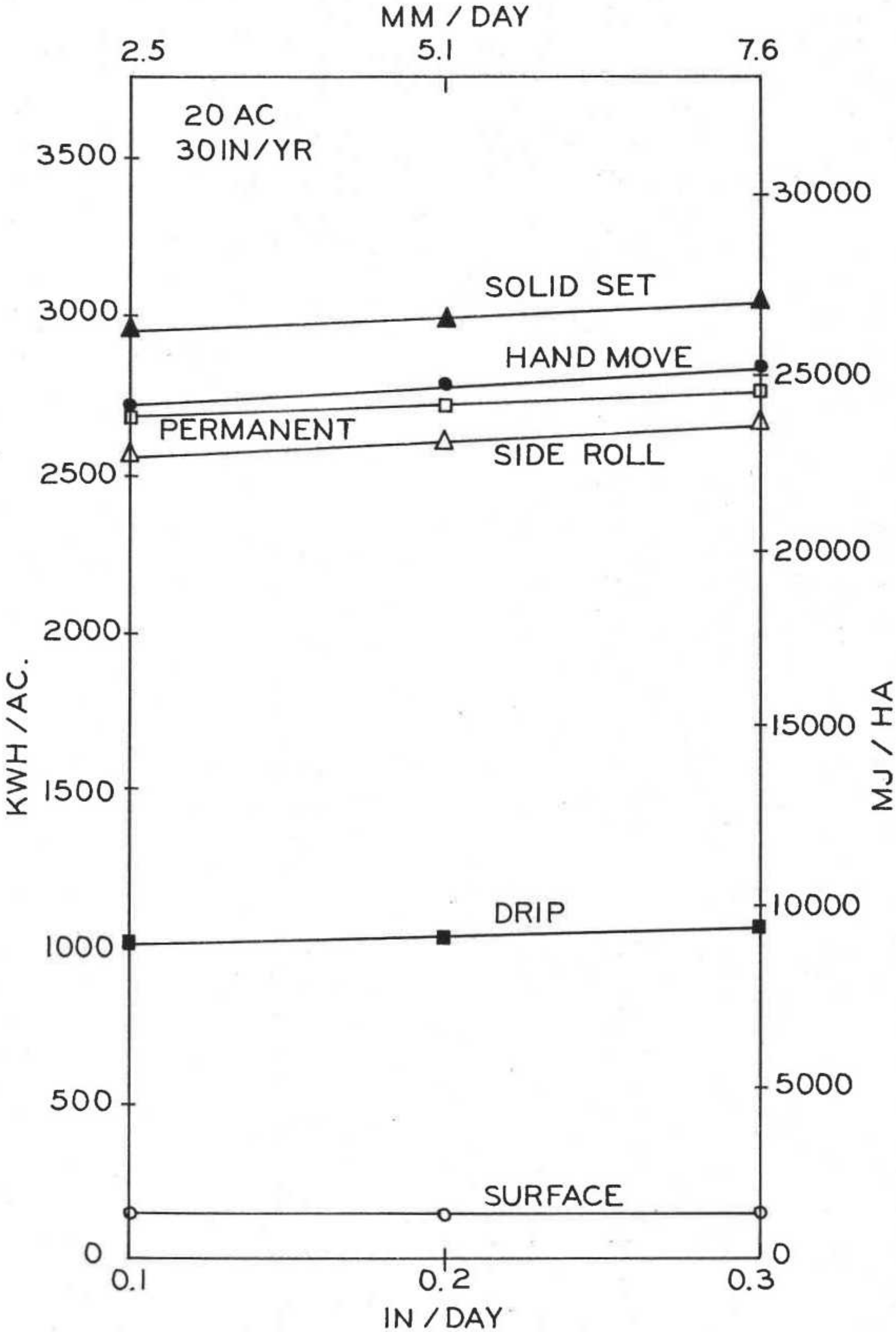

Figure 4. Plot of total seasonal energy as a function of consumptive use rate for a 30 inch (762 mm) seasonal application on a 20 acre (8.1 ha.) field.

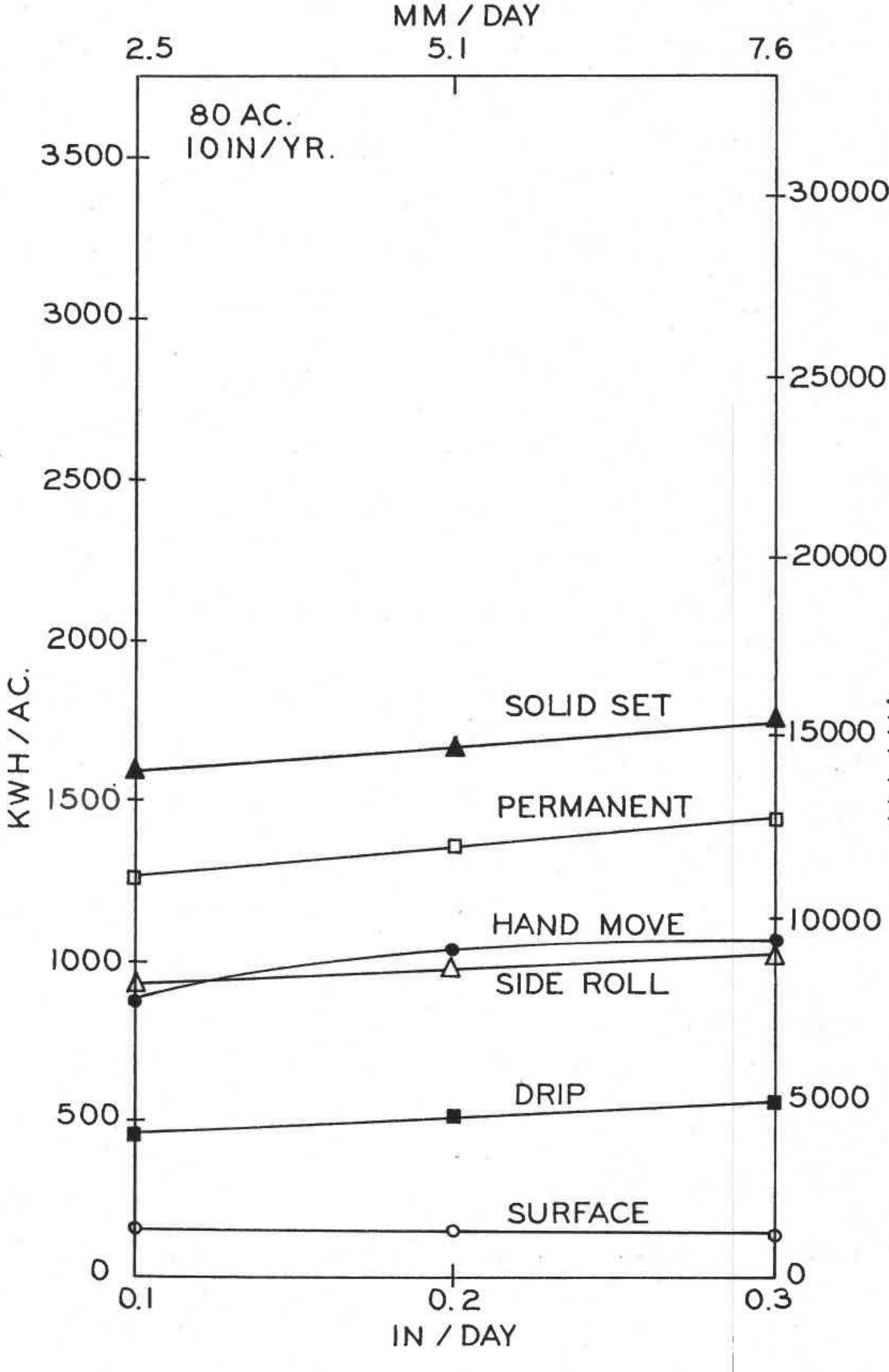

Figure 5. Plot of total seasonal energy as a function of consumptive use rate for a 10 inch (254 mm) seasonal application on a 80 acre (32.4 ha.) field.

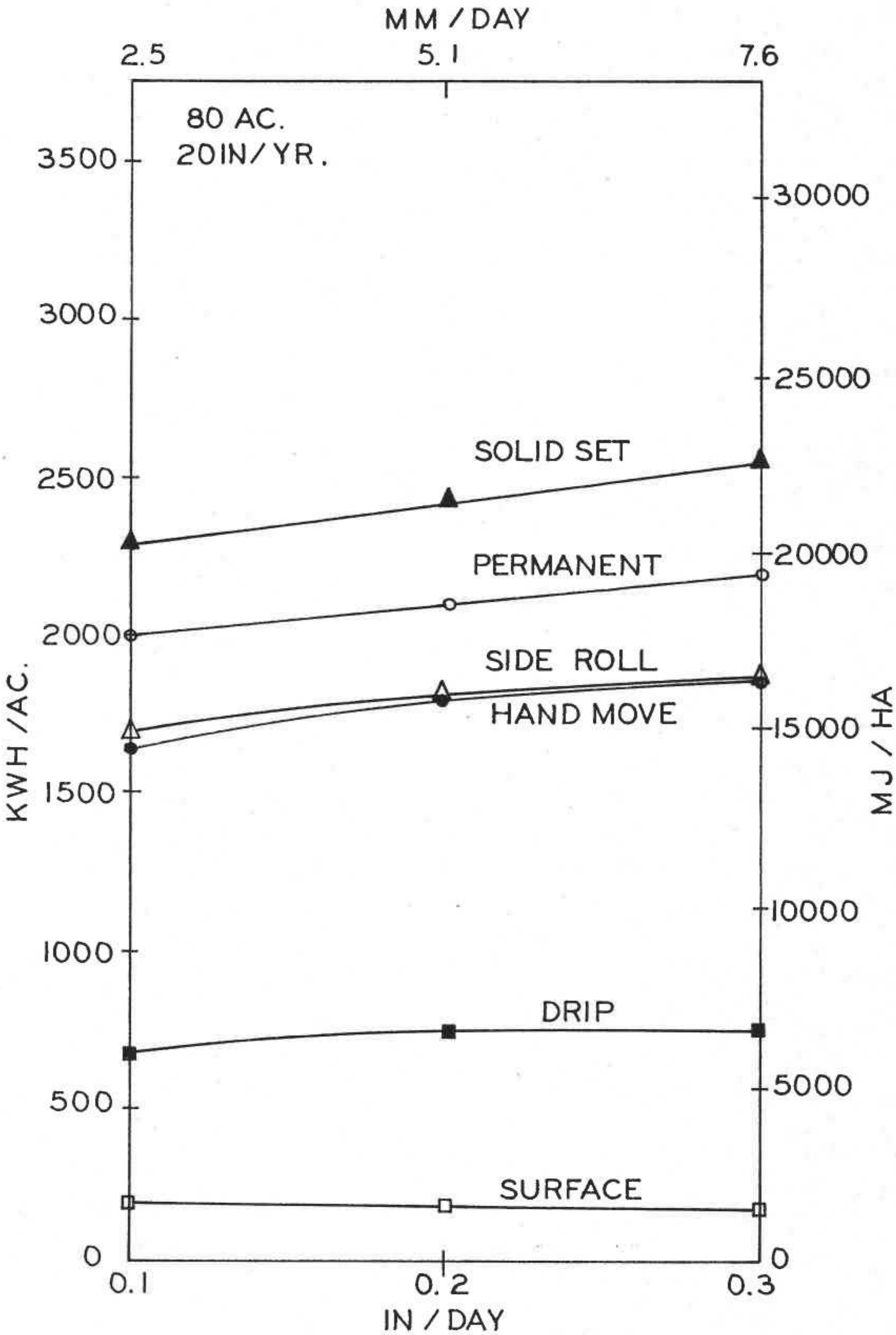

Figure 6. Plot of total seasonal energy as a function of consumptive use rate for a 20 inch (508 mm) seasonal application on a 80 acre (32.4 ha.) field.

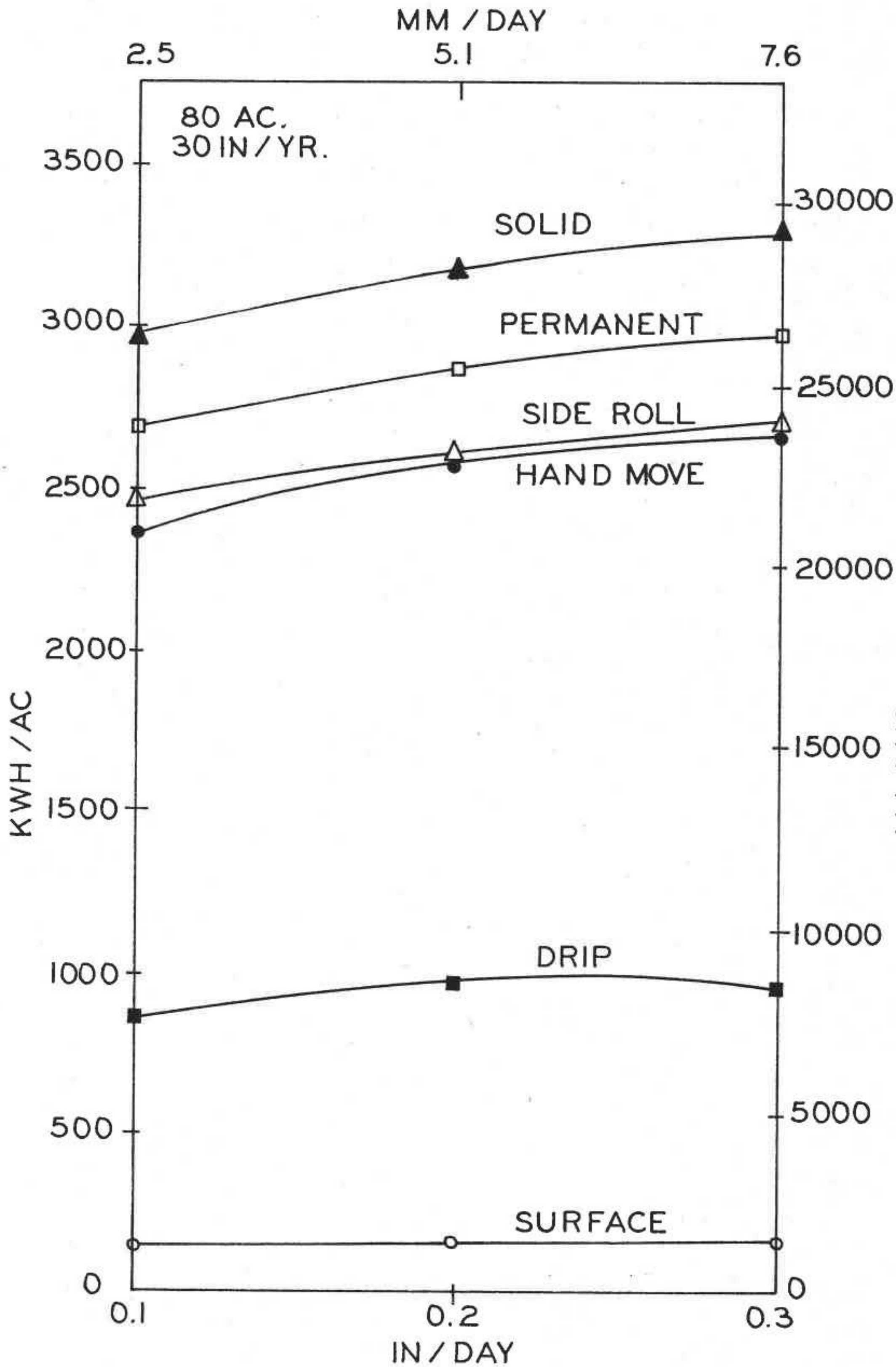

Figure 7. Plot of total seasonal energy as a function of consumptive use rate for a 30 inch (762 mm) seasonal application on a 80 acre (32.4 ha.) field.

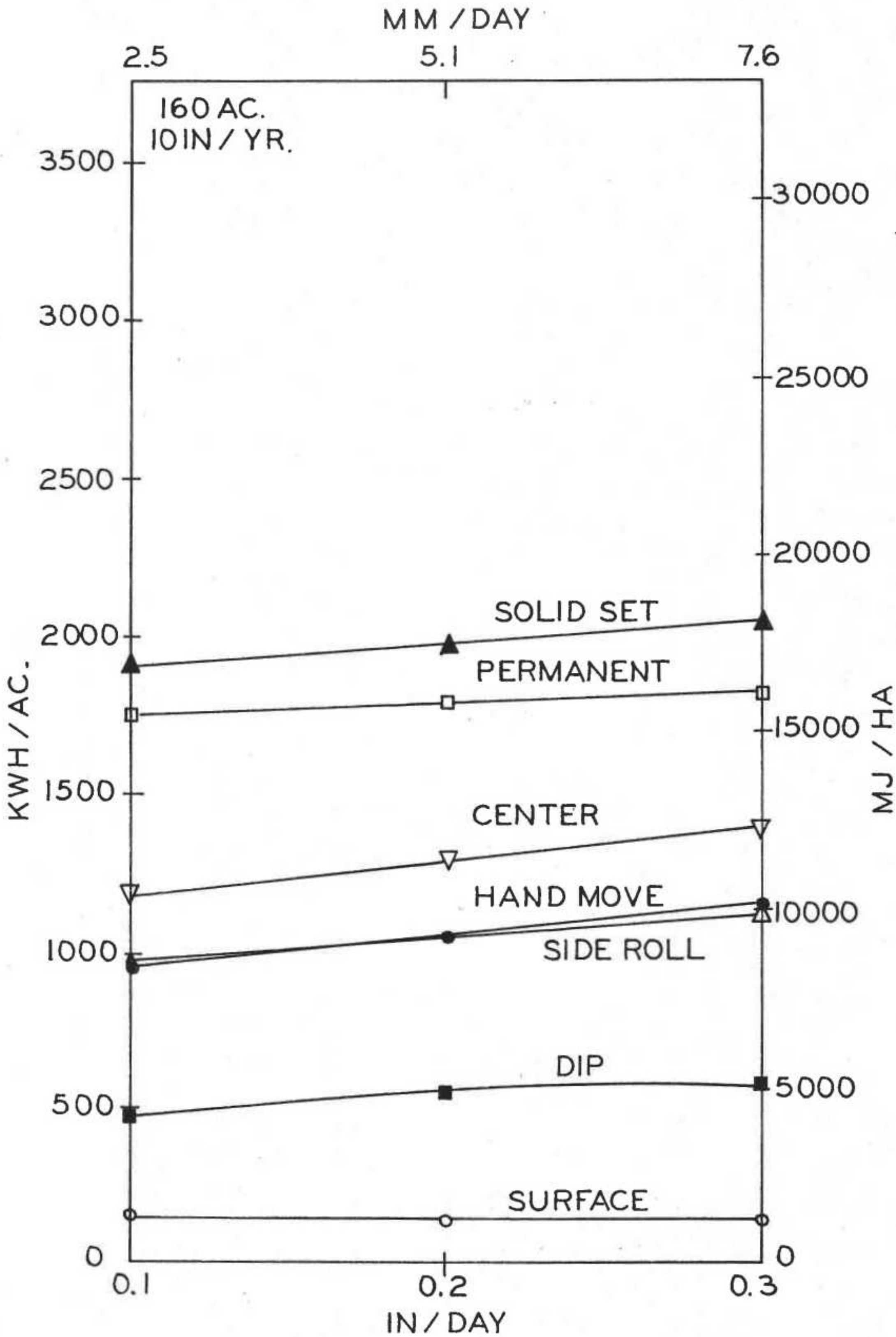

Figure 8. Plot of total seasonal energy as a function of consumptive use rate for a 10 inch (254 mm) seasonal application on a 160 acre (64.8 ha.) field.

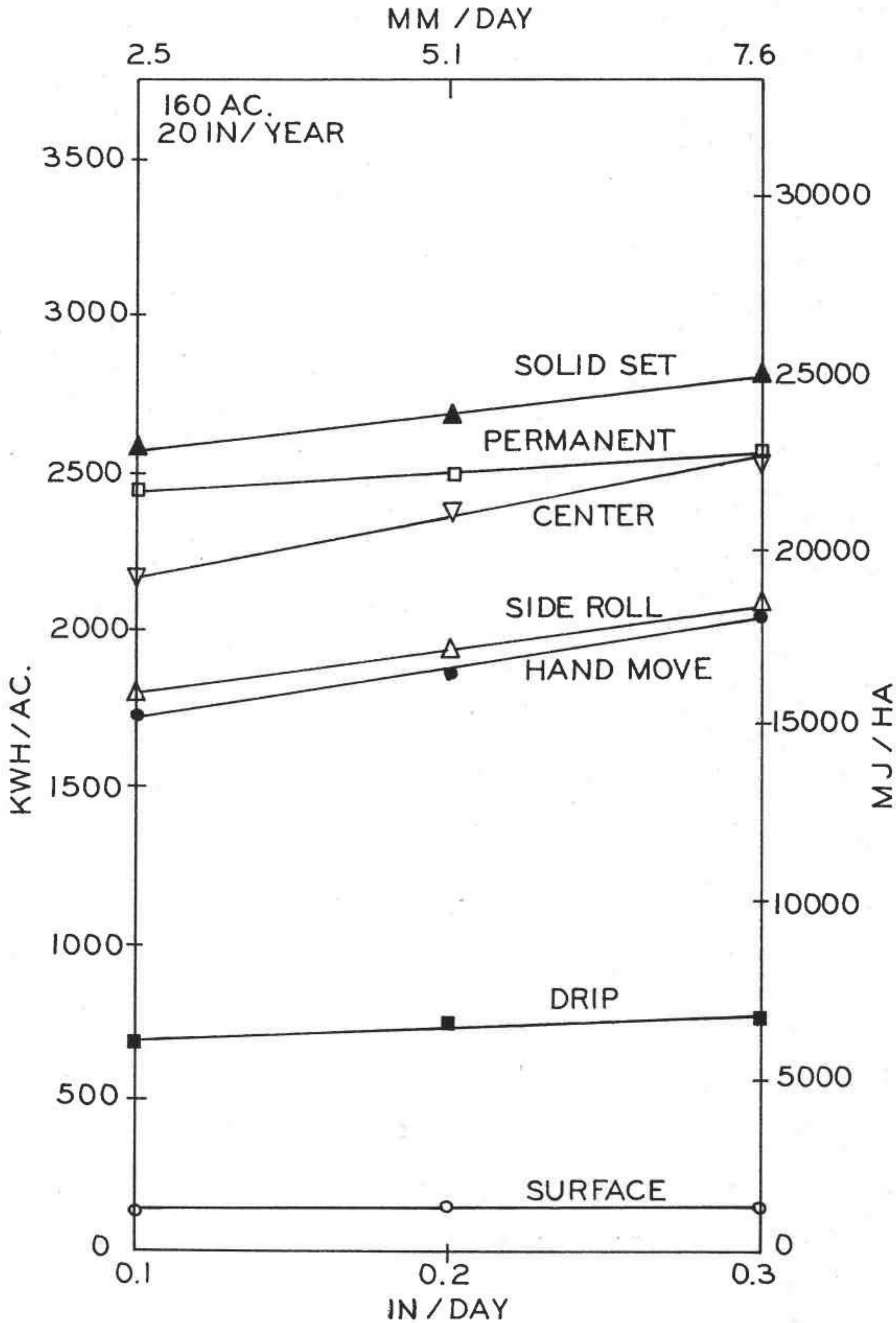

Figure 9. Plot of total seasonal energy as a function of consumptive use rate for a 20 inch (508 mm) seasonal application on a 160 acre (64.8 ha.) field.

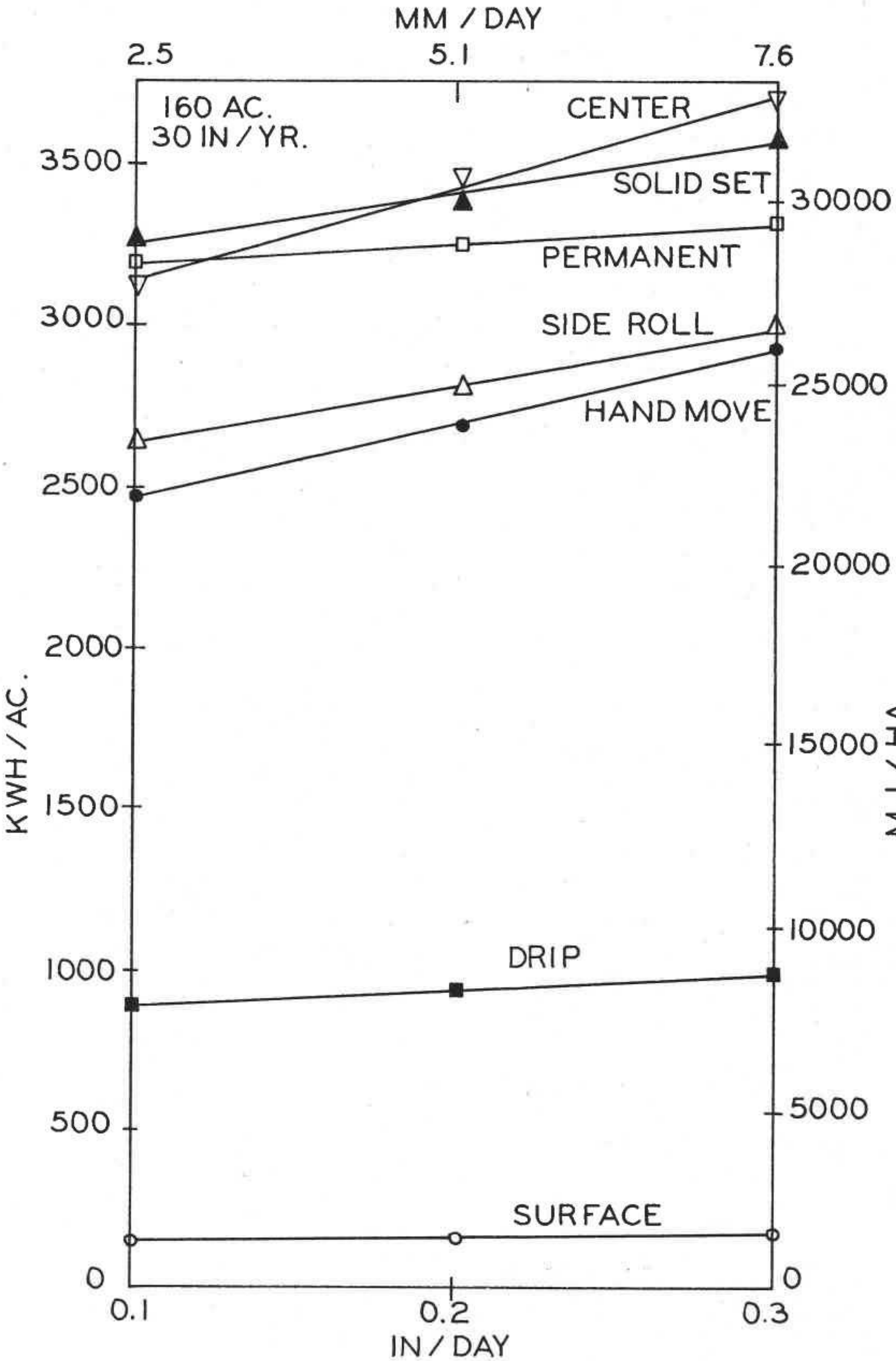

Figure 10. Plot of total seasonal energy as a function of consumptive use rate for a 30 inch (762 mm) seasonal application on a 160 acre (64.8 ha.) field.

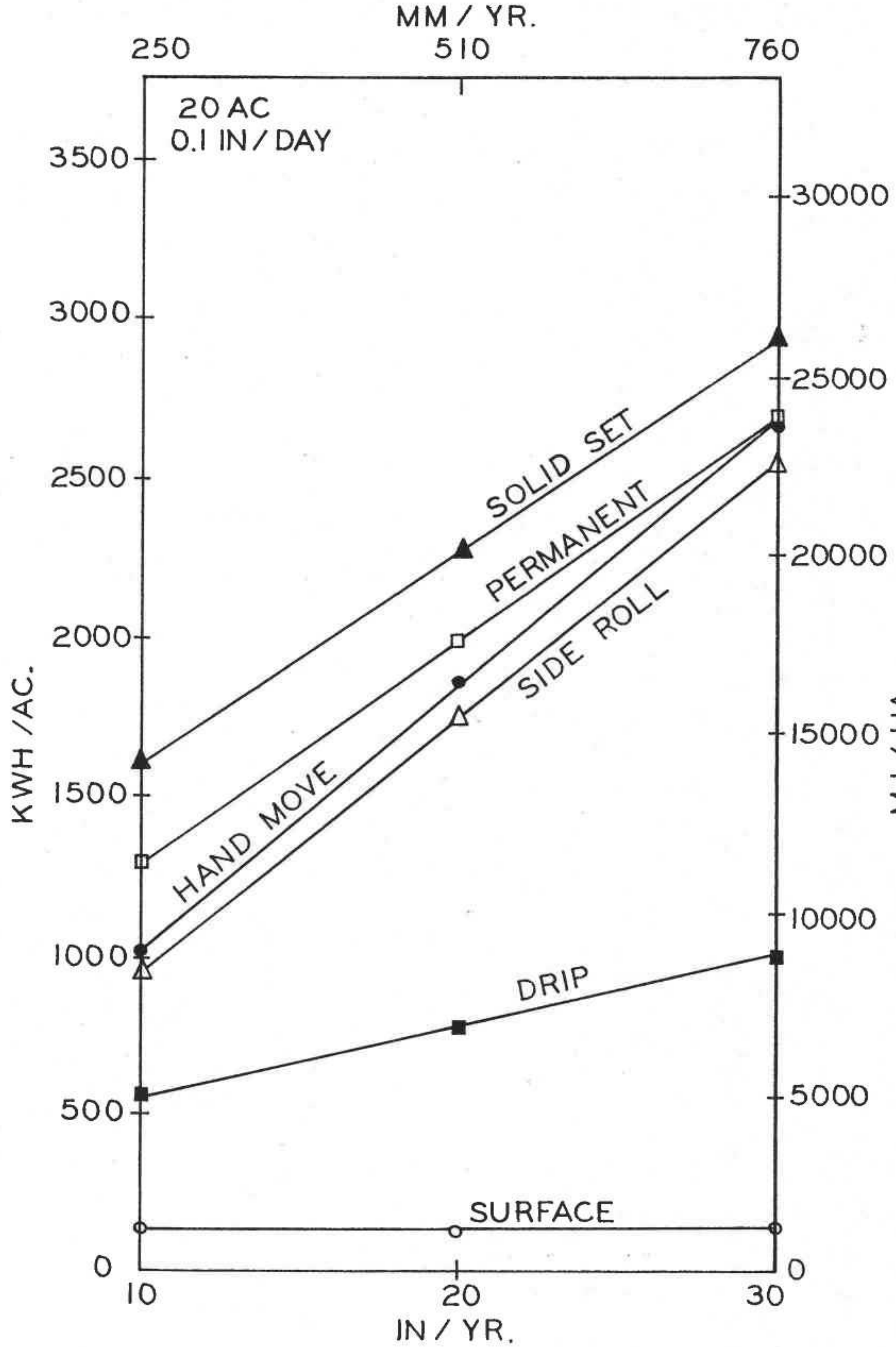

Figure 11. Plot of total seasonal energy as a function of seasonal application on a 20 acre (8.1 ha.) field with a consumptive use rate of 0.1 inch (2.5 mm) per day.

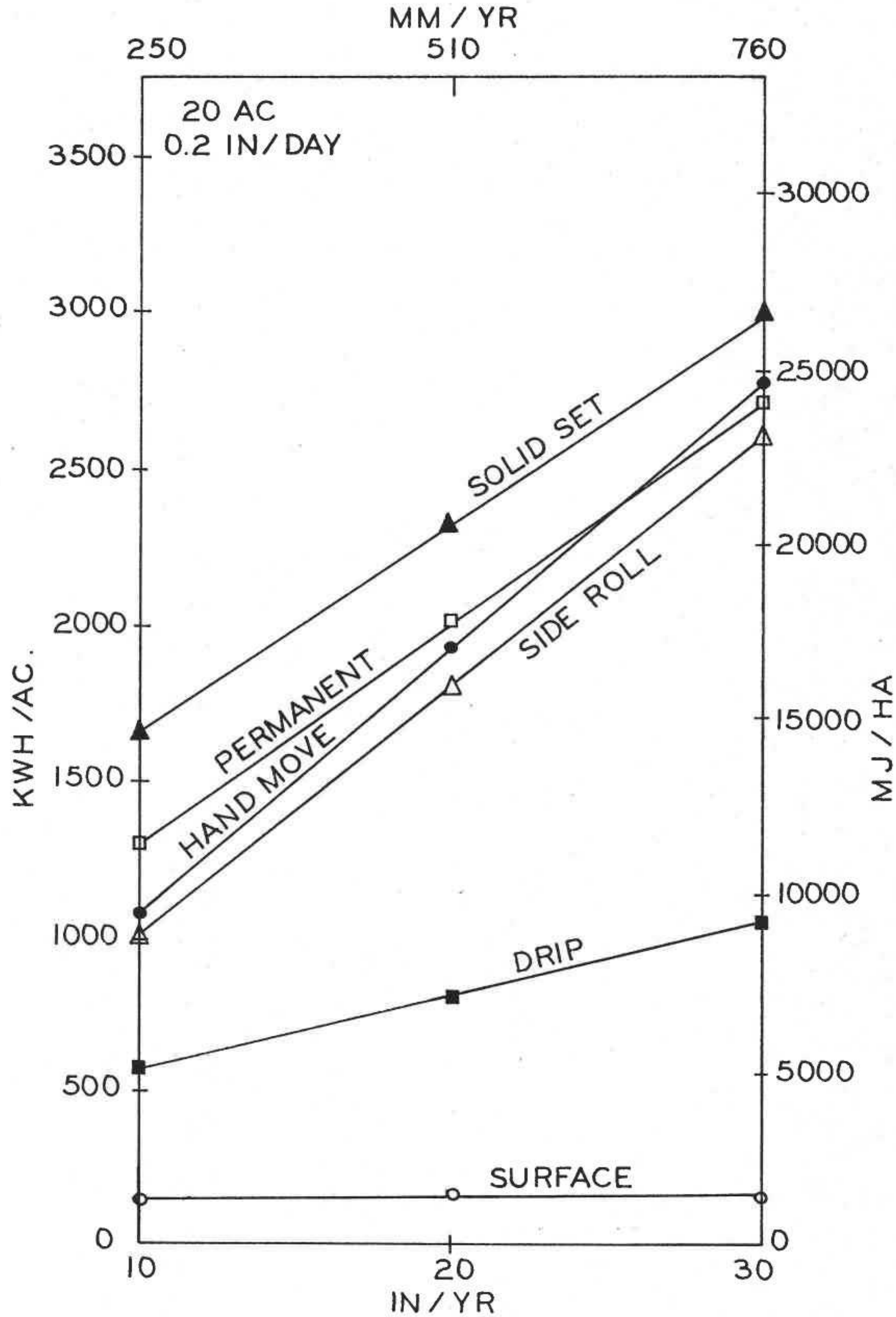

Figure 12. Plot of total seasonal energy as a function of seasonal application on a 20 acre (8.1 ha.) field with a consumptive use rate of 0.2 inch (5.1 mm) per day.

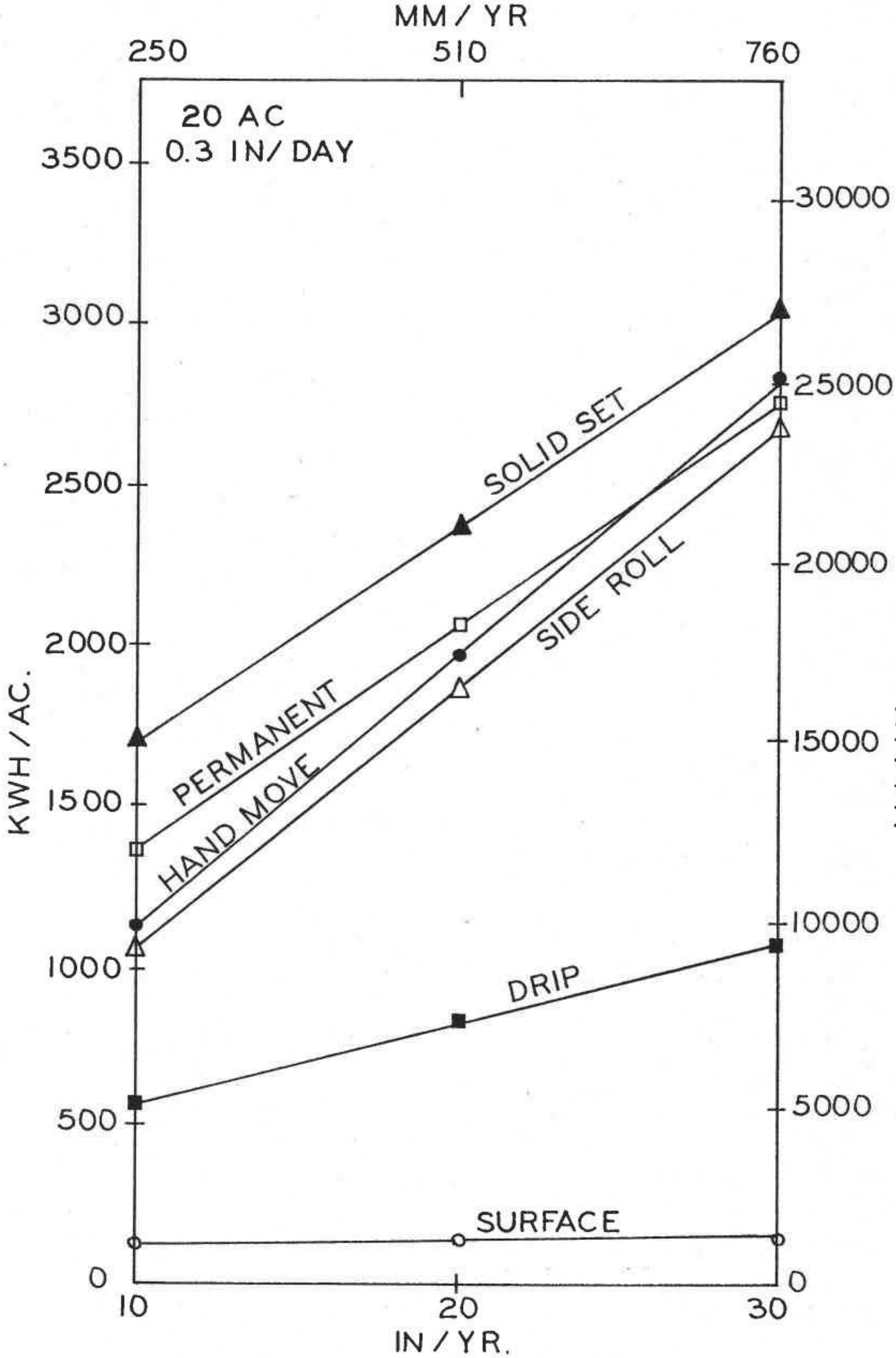

Figure 13. Plot of total seasonal energy as a function of seasonal application on a 20 acre (8.1 ha.) field with a consumptive use rate of 0.3 inch (7.6 mm) per day.

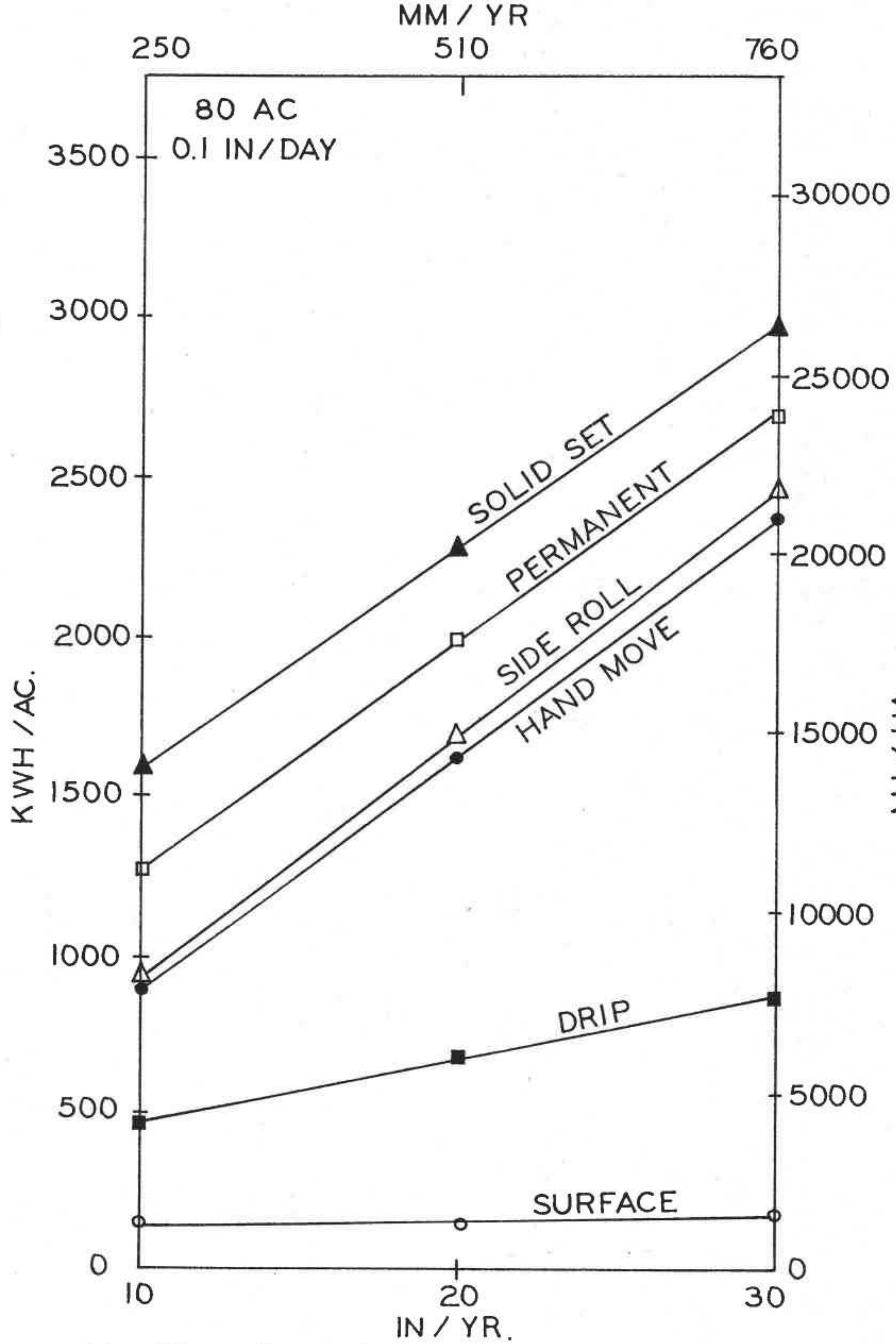

Figure 14. Plot of total seasonal energy as a function of seasonal application on a 80 acre (32.4 ha.) field with a consumptive use rate of 0.1 inch (2.5 mm) per day.

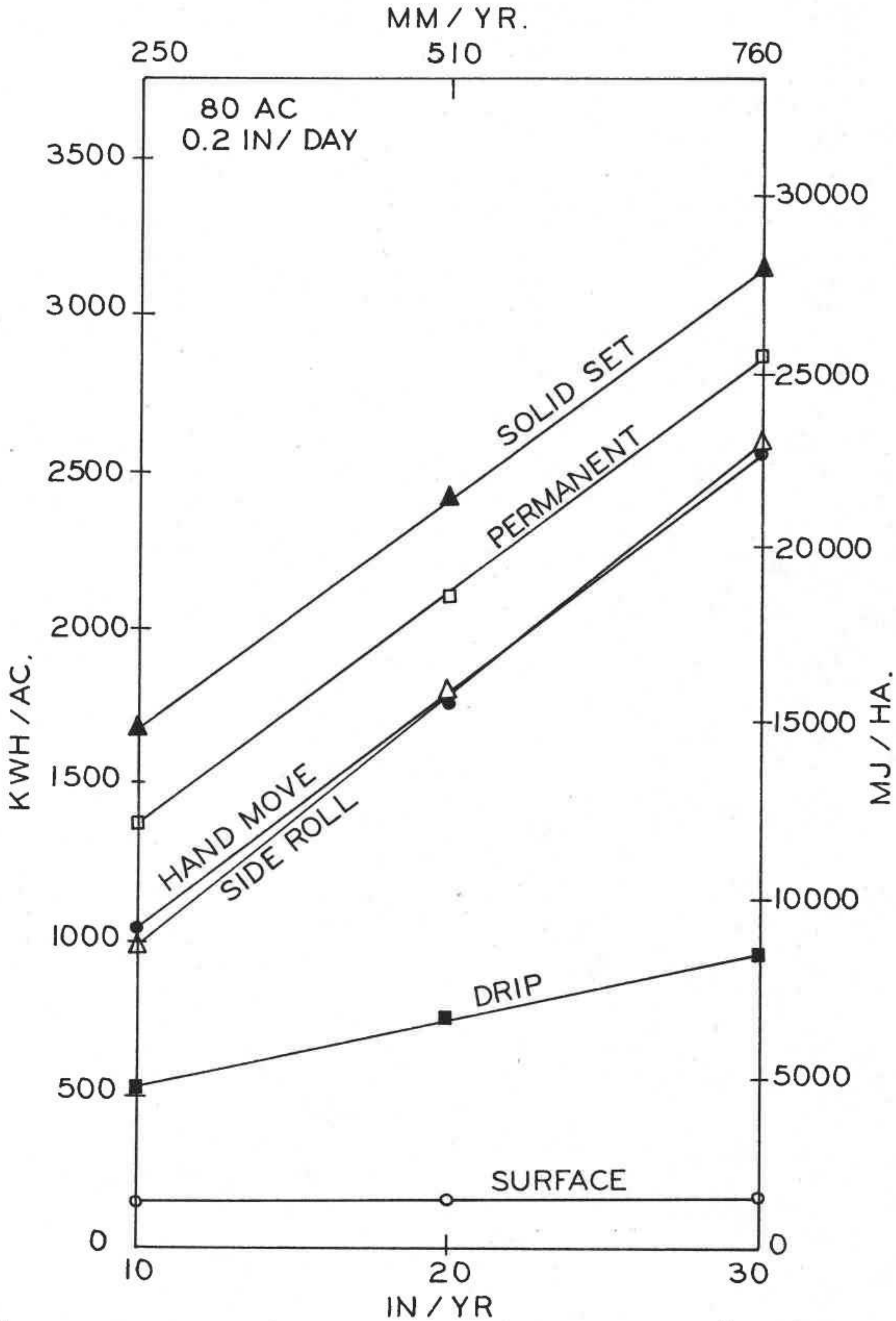

Figure 15. Plot of total seasonal energy as a function of seasonal application on a 80 acre (32.4 ha.) field with a consumptive use rate of 0.2 inch (5.1 mm) per day.

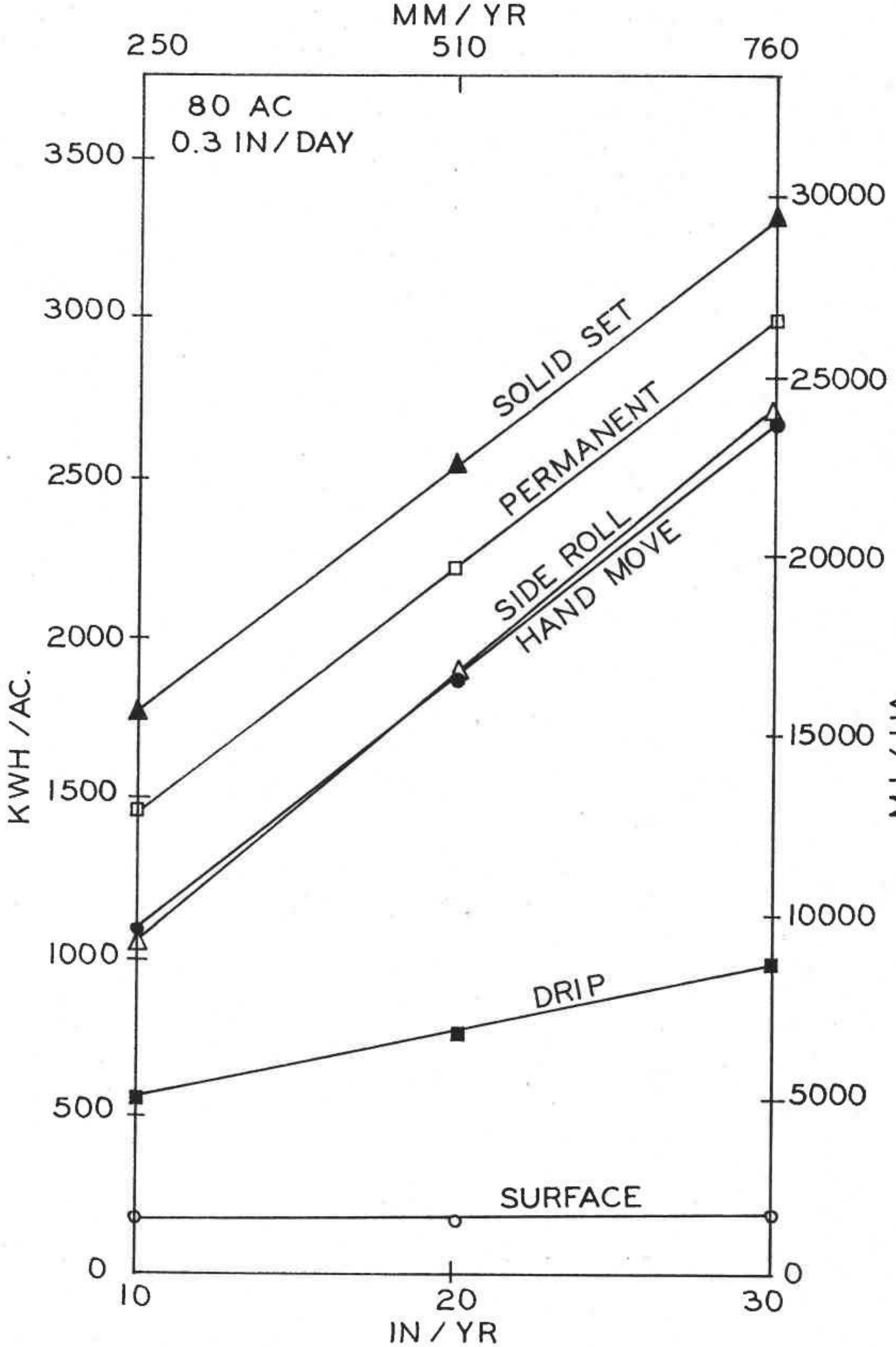

Figure 16. Plot of total seasonal energy as a function of seasonal application on a 80 acre (32.4 ha.) field with a consumptive use rate of 0.3 inch (7.6 mm) per day.

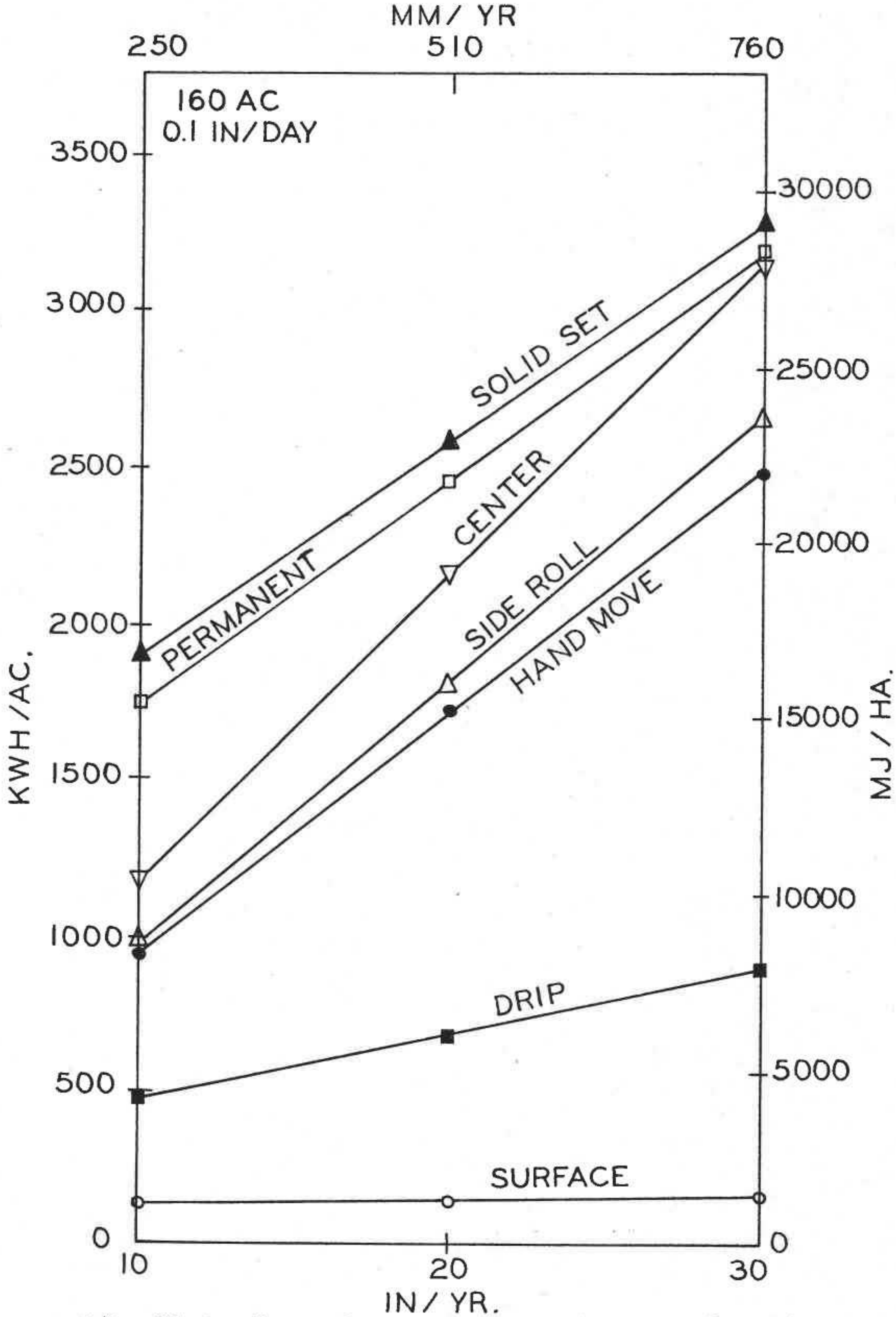

Figure 17. Plot of total seasonal energy as a function of seasonal application on a 160 acre (64.8 ha.) field with a consumptive use rate of 0.1 inch (2.5 mm) per day.

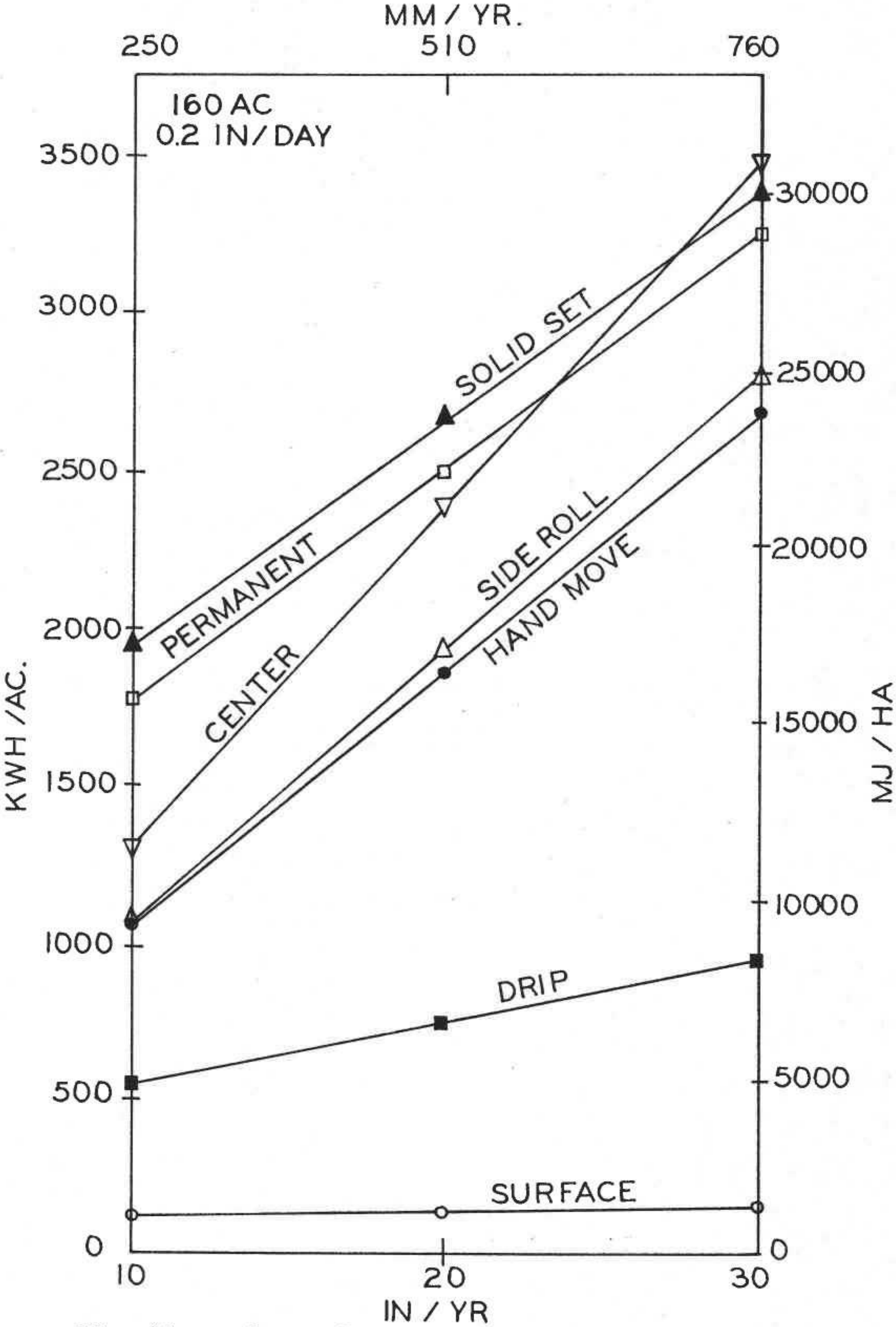

Figure 18. Plot of total seasonal energy as a function of seasonal application on a 160 acre (64.8 ha.) field with a consumptive use rate of 0.2 inch (5.1 mm) per day.

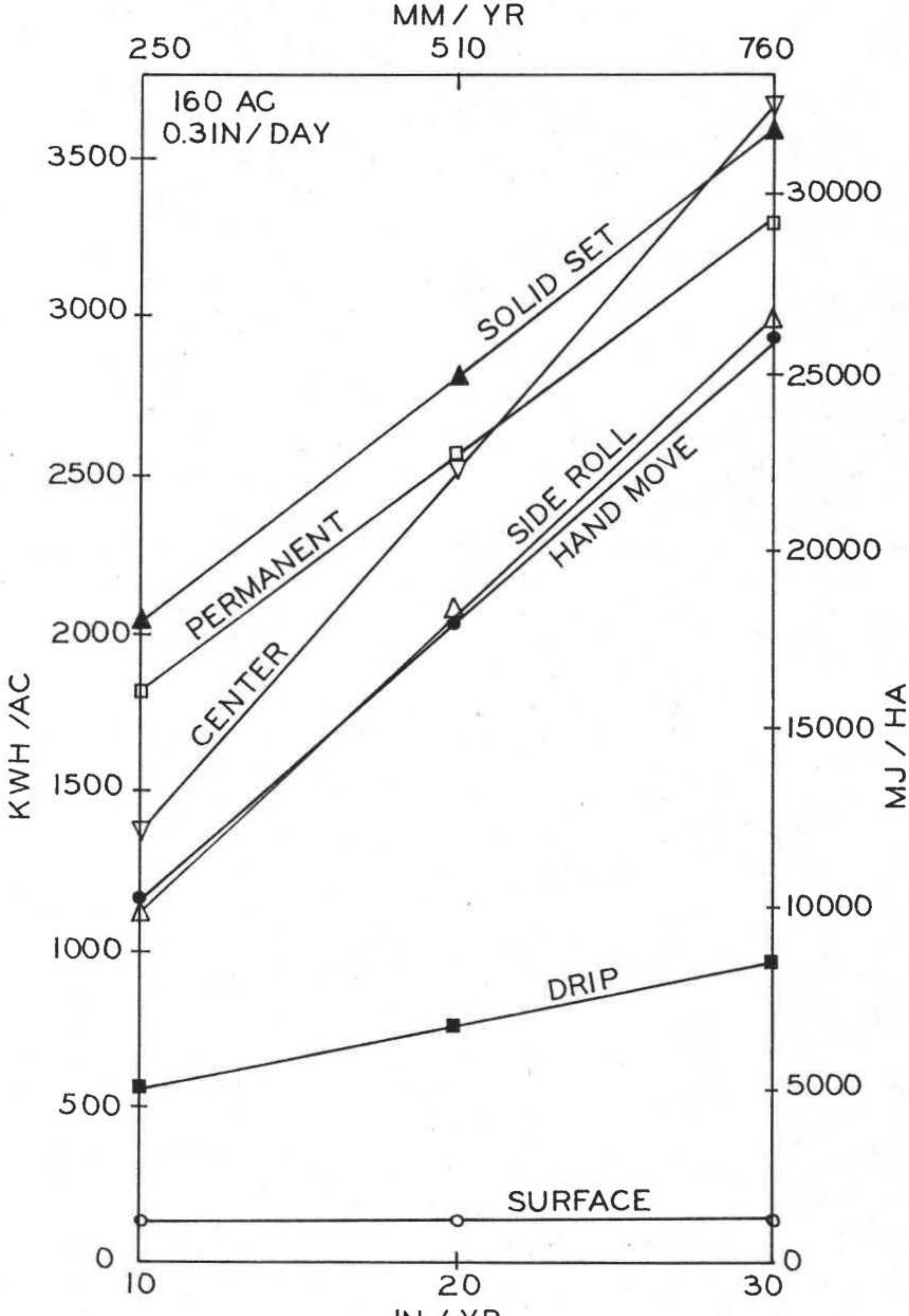

Figure 19. Plot of total seasonal energy as a function of seasonal application on a 160 acre (64.8 ha.) field with a consumptive use rate of 0.3 inch (7.6 mm) per day.

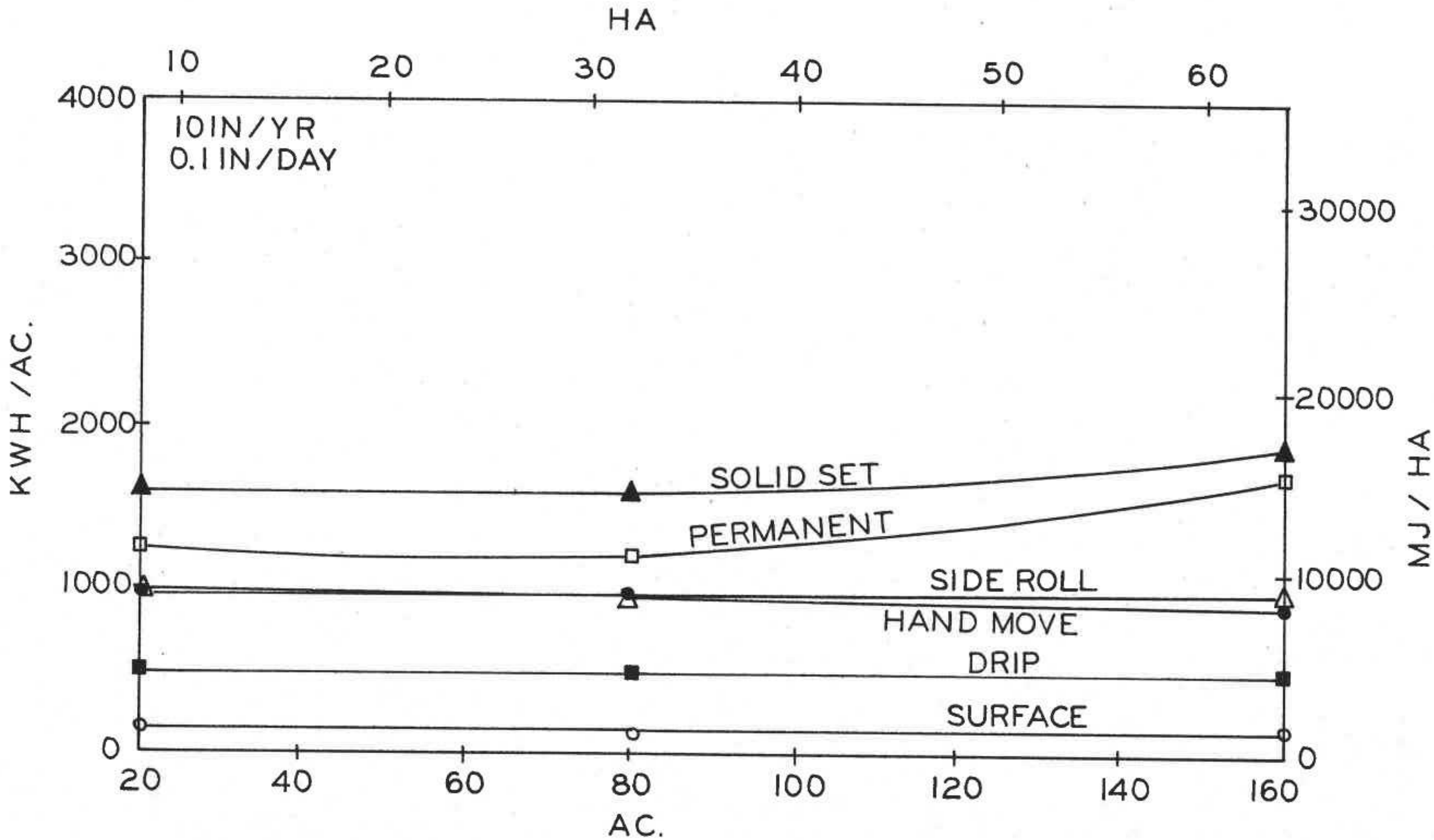

Figure 20. Plot of total seasonal energy as a function of area irrigated for a 10 inch (254 mm) seasonal application with a consumptive use rate of 0.1 inch (2.5 mm) per day.

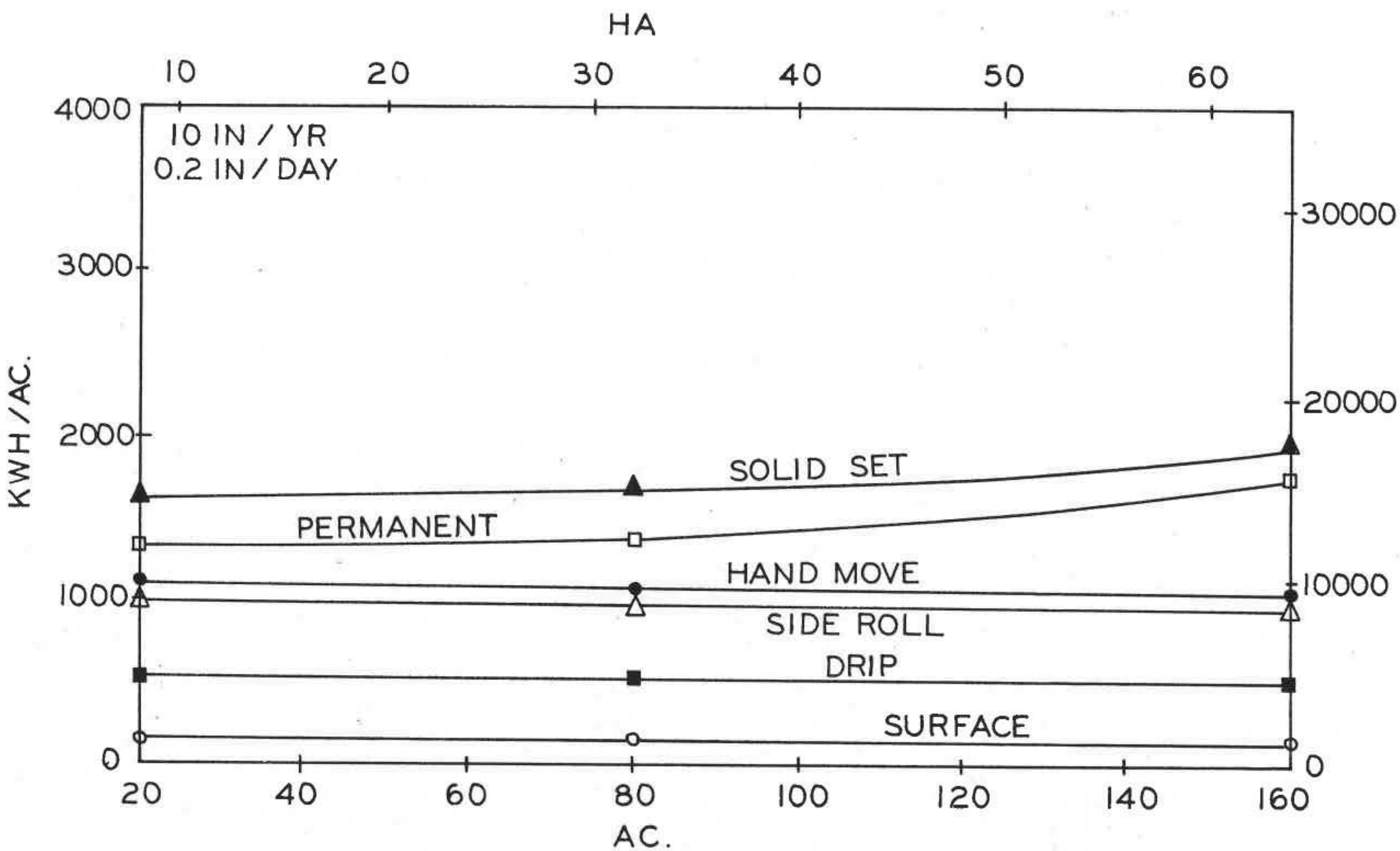

Figure 21. Plot of total seasonal energy as a function of area irrigated for a 10 inch (254 mm) seasonal application with a consumptive use rate of 0.2 inch (5.1 mm) per day.

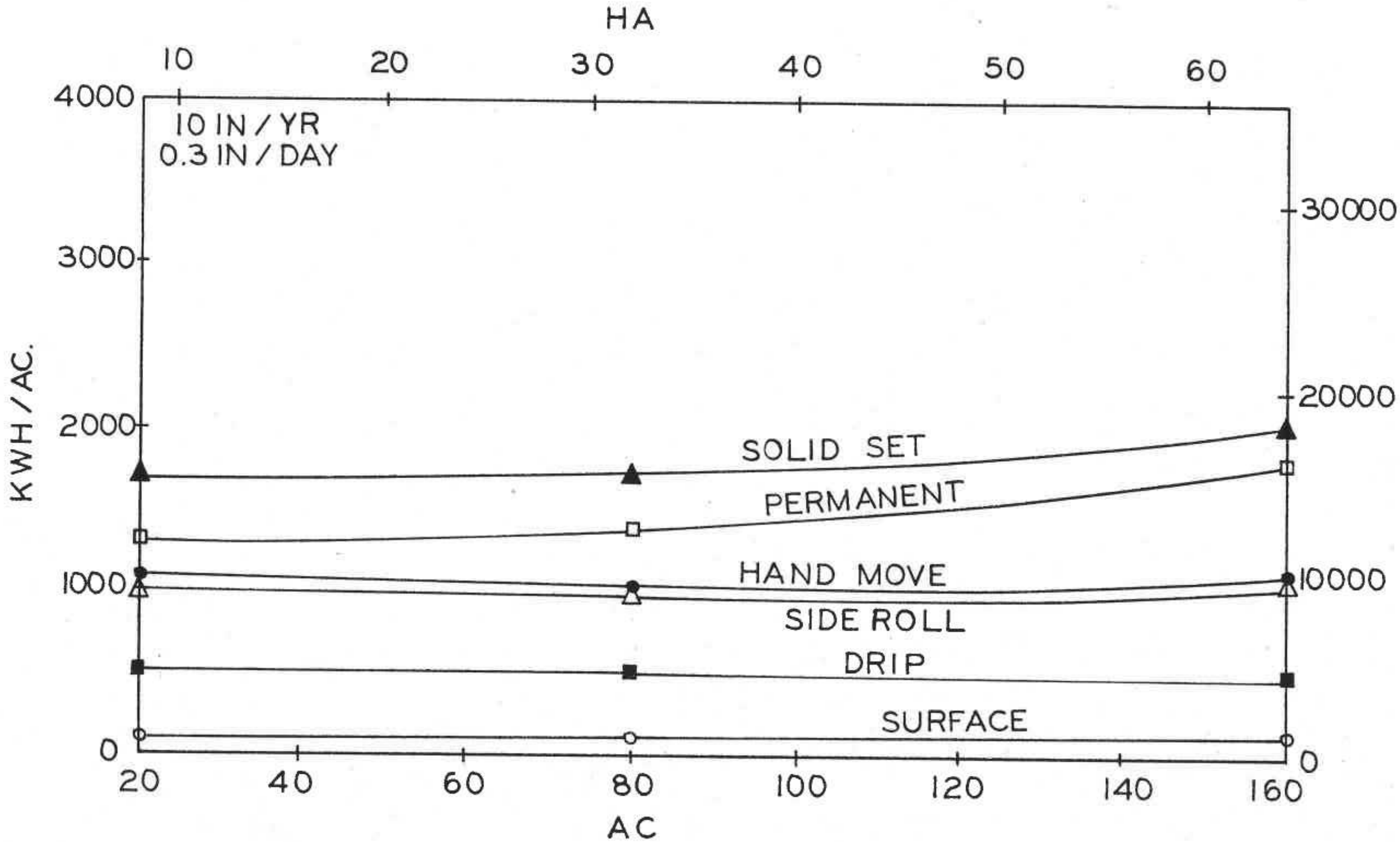

Figure 22. Plot of total seasonal energy as a function of area irrigated for a 10 inch (254 mm) seasonal application with a consumptive use rate of 0.3 inch (7.6 mm) per day.

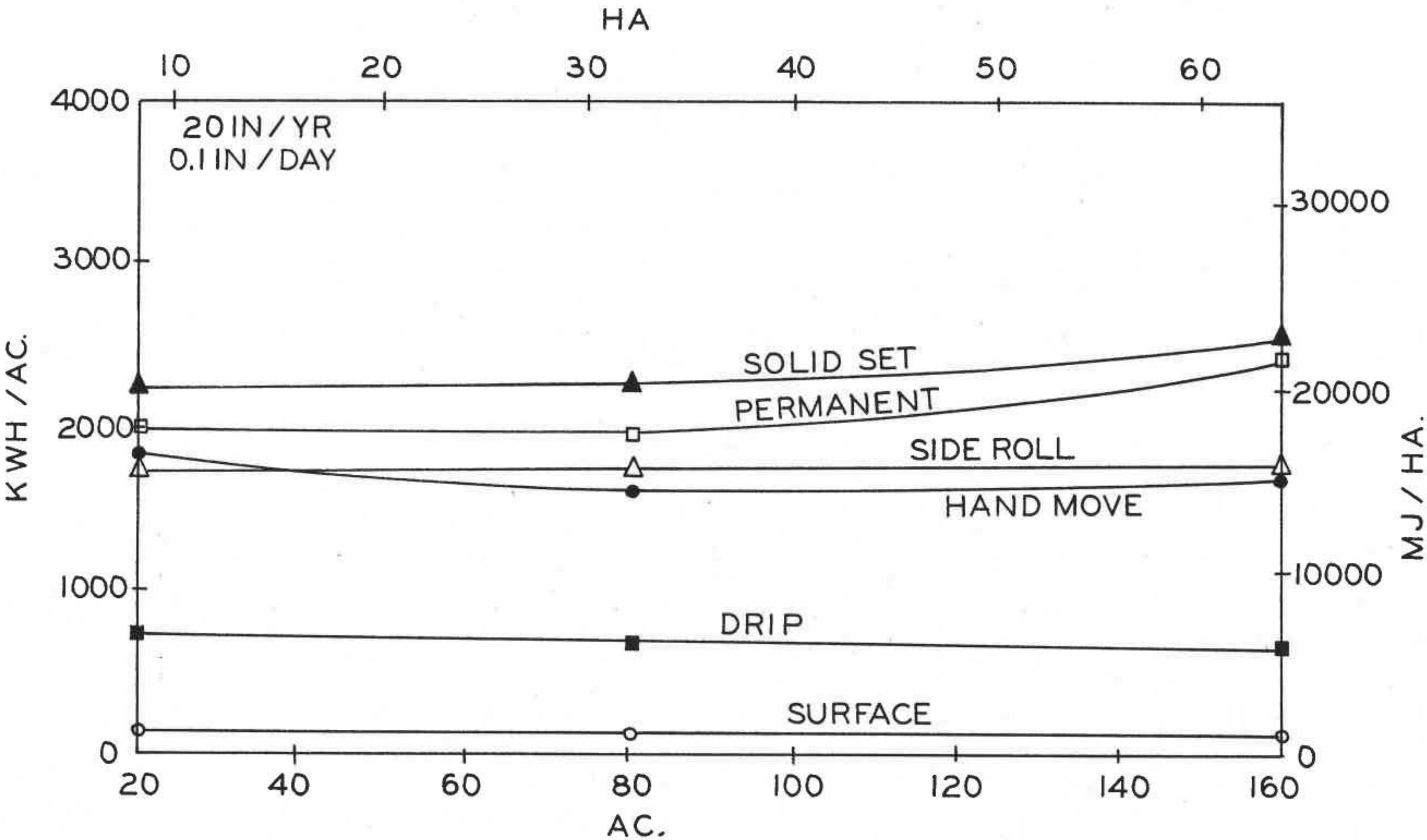

Figure 23. Plot of total seasonal energy as a function of area irrigated for a 20 inch (508 mm) seasonal application with a consumptive use rate of 0.1 inch (2.5 mm) per day.

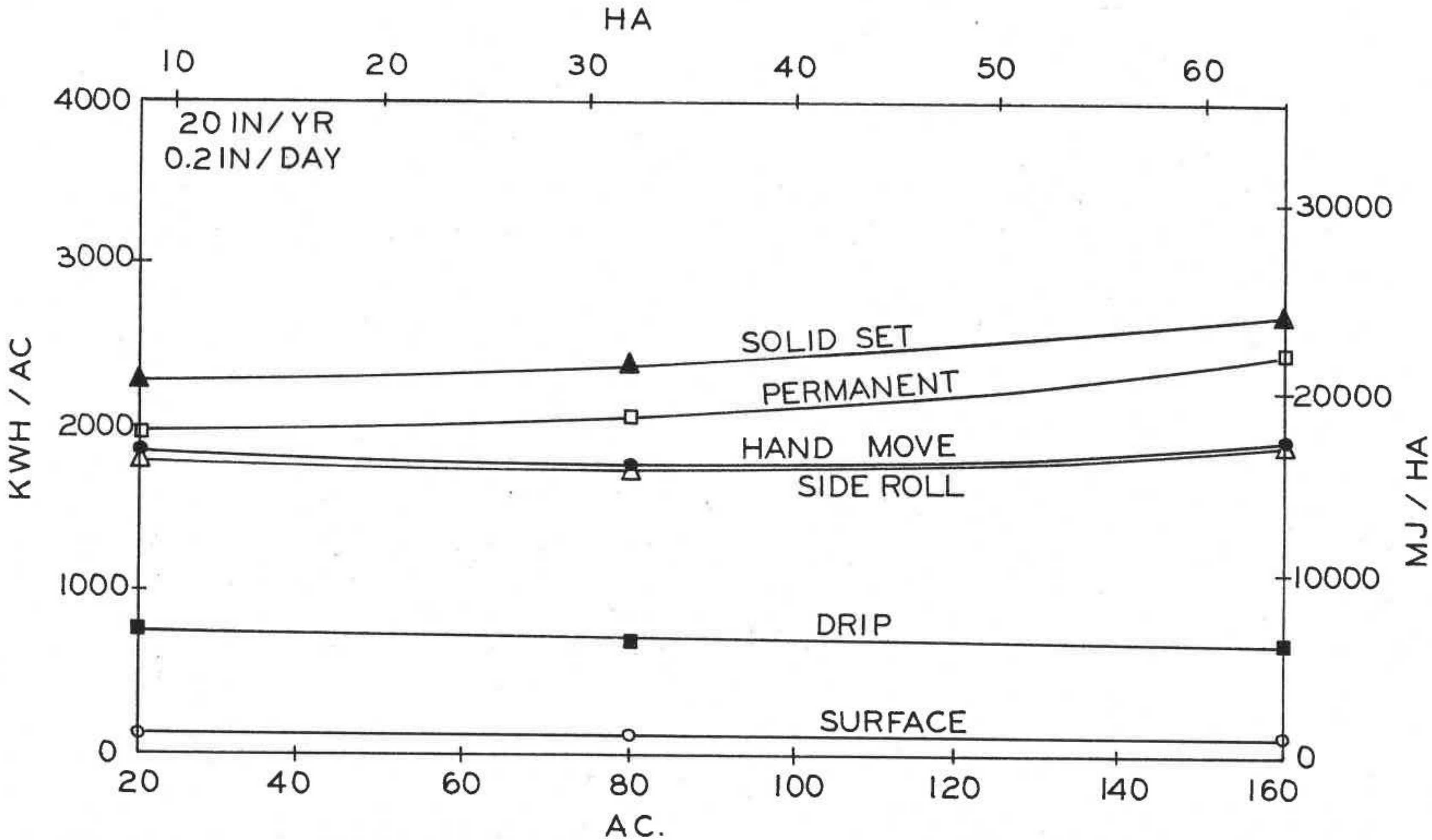

Figure 24. Plot of total seasonal energy as a function of area irrigated for a 20 inch (508 mm) seasonal application with a consumptive use rate of 0.2 inch (5.1 mm) per day.

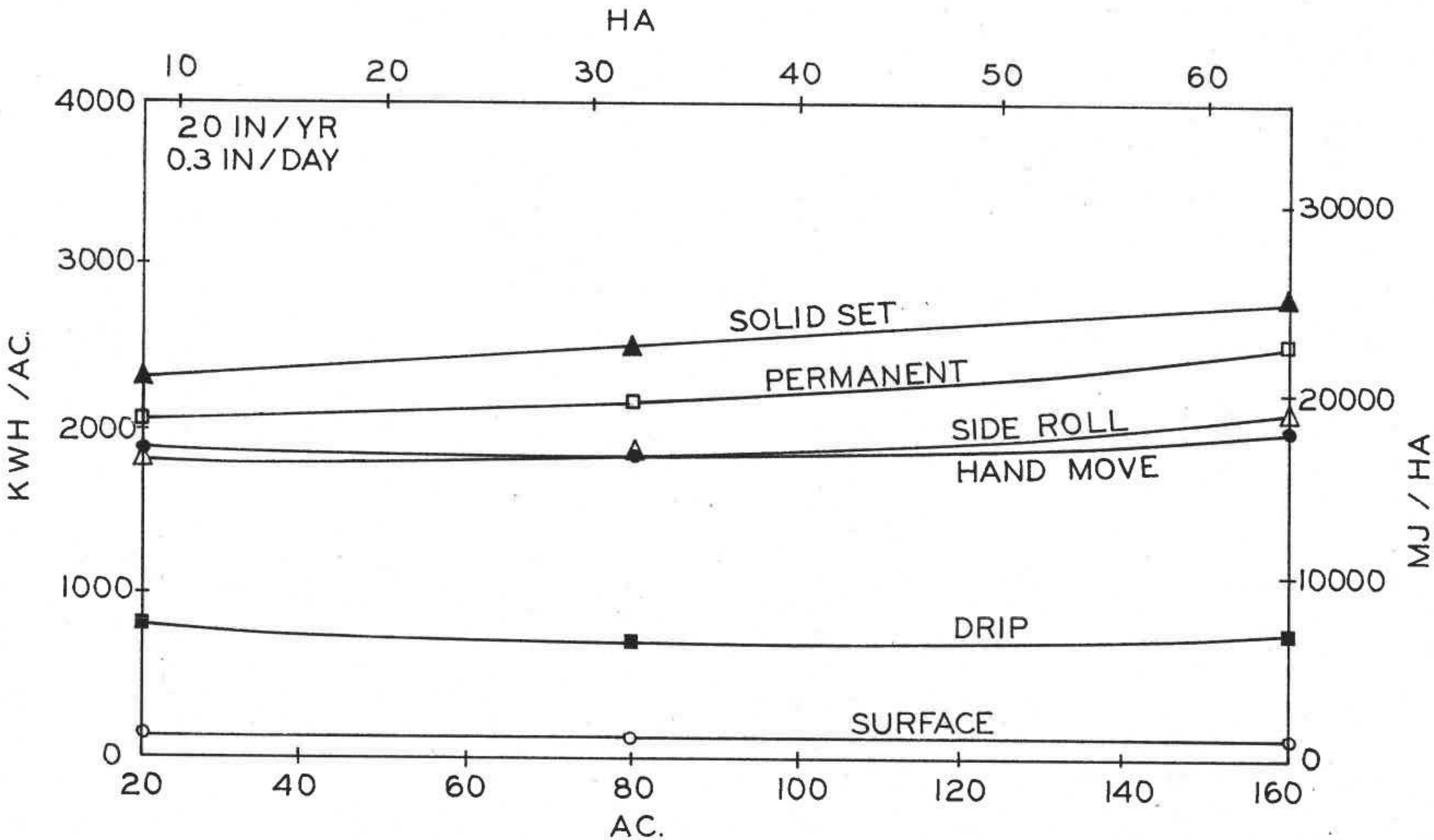

Figure 25. Plot of total seasonal energy as a function of area irrigated for a 20 inch (508 mm) seasonal application with a consumptive use rate of 0.3 inch (7.6 mm) per day.

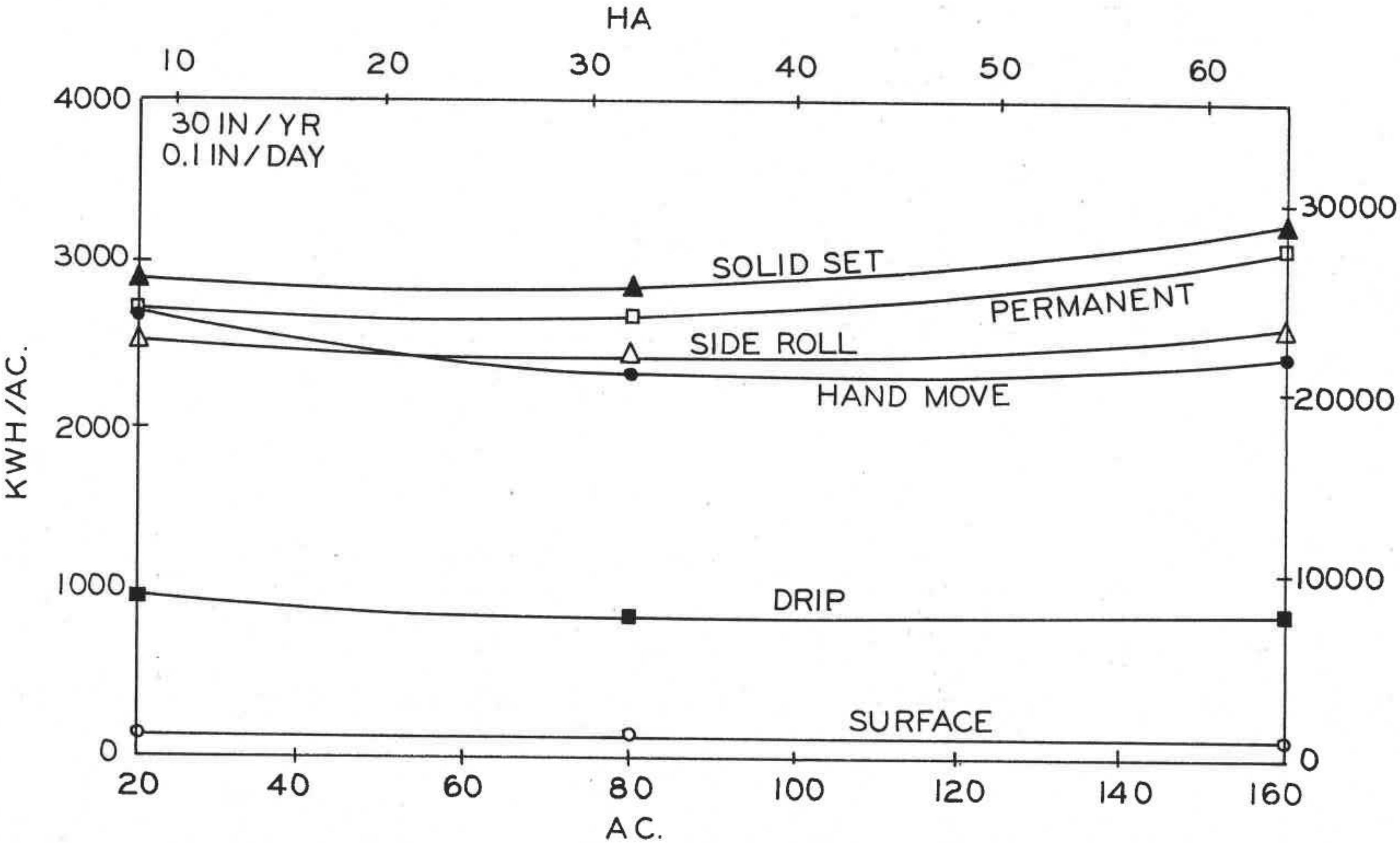

Figure 26. Plot of total seasonal energy as a function of area irrigated for a 30 inch (762 mm) seasonal application with a consumptive use rate of 0.1 inch (2.5 mm) per day.

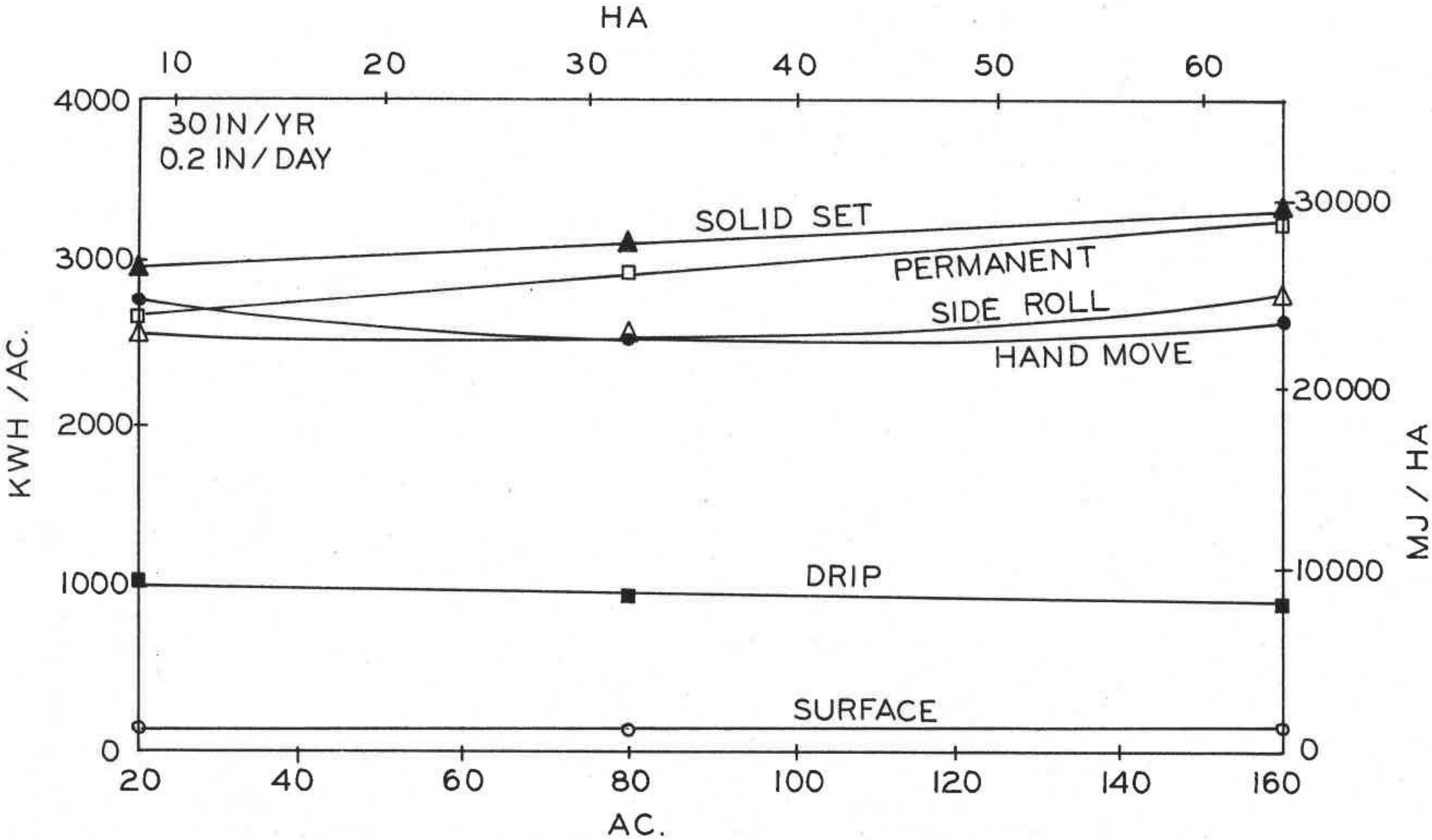

Figure 27. Plot of total seasonal energy as a function of area irrigated for a 30 inch (762 mm) seasonal application with a consumptive use rate of 0.2 inch (5.1 mm) per day.

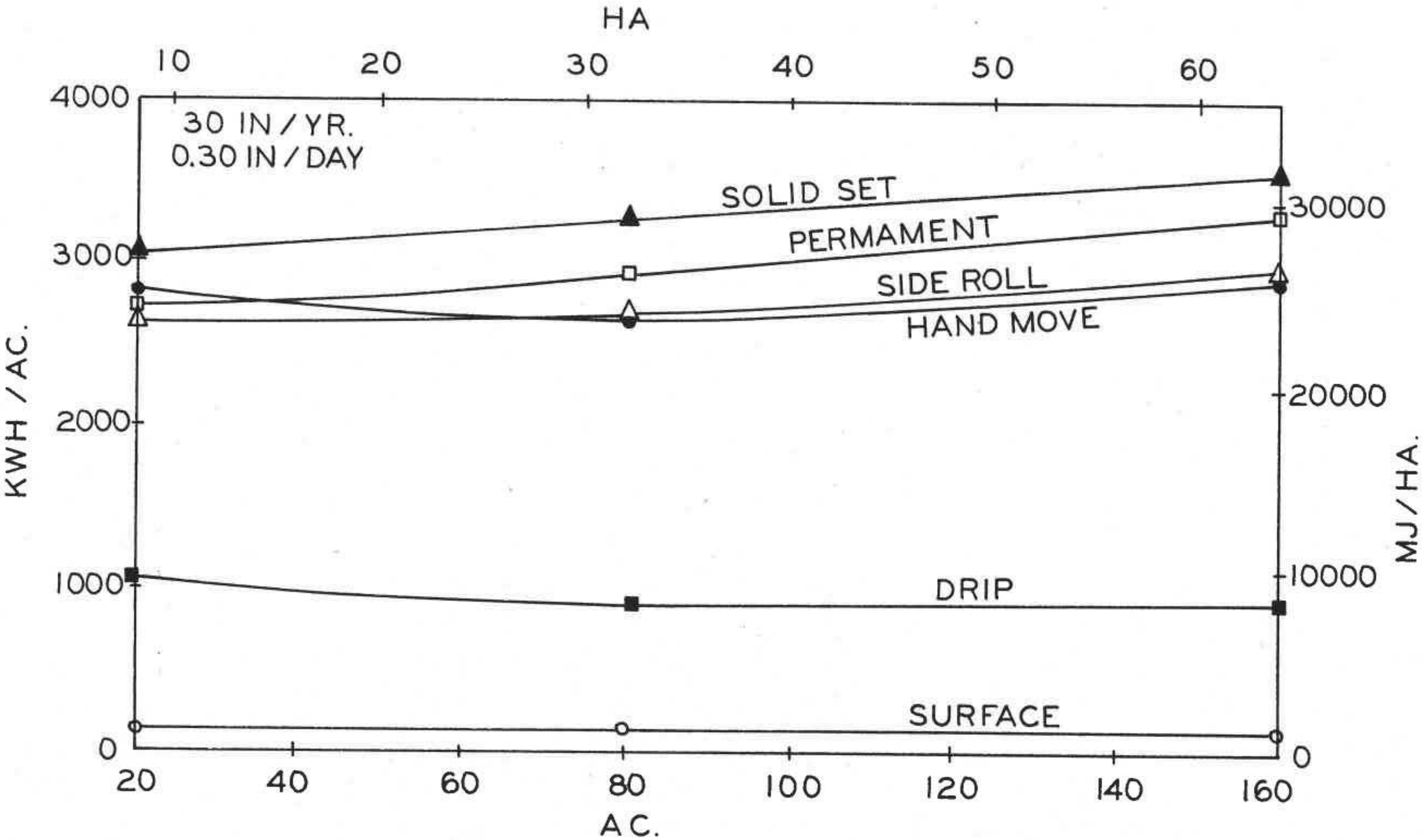

Figure 28. Plot of total seasonal energy as a function of area irrigated for a 30 inch (762 mm) seasonal application with a consumptive use rate of 0.3 inch (7.6 mm) per day.

slightly lower level of energy input, since it requires less equipment in the form of wheels and moving devices, and the side roll laterals are of heavier gauge material. Instead, Figures 21 and 22 show the hand move system requiring more energy than the side roll system. Figure 20 and Figures 23-28 show the hand move system requiring less energy on larger acreages and at higher application levels than the side roll system, but more energy on smaller fields and at lower application levels. This behavior appears due to insufficient detail in the approximation of transport energy for the hand move system. A single energy requirement per lateral per irrigation was assumed for transportation. This value appears to have been somewhat too liberal for the shorter laterals used in small fields. The error does not appear to greatly affect the system at higher application levels, as the other energy parameters involved are large in those cases to make transport energy insignificant. At lower application levels, transport energy is proportionally a much larger input, and significantly affects results.

There is an interesting relationship among the center pivot, solid set and permanent sprinkler systems for the 160-acre field, shown in Figures 17-19. For lower total applications and lower consumptive use rates, the center pivot system requires less energy than the two stationary systems, but requires more energy at higher levels of application and consumptive use. This relationship is probably a valid one, and could logically be expected. The solid set and permanent sprinkler systems initially require substantial energy expenditures due to the large number of laterals in these systems. The center pivot system requires less energy initially for its single lateral, even though it is more sophisticated equipment than found in other systems. The center pivot system requires more energy to operate on an annual basis, because of its higher pressure requirement.

For a 10-inch seasonal application, with a consumptive use rate of 0.3 inches per day, pumping energy requires 82 percent of a center pivot system's total energy requirement; whereas, pumping energy is responsible for only 39 percent of a solid set system's total energy requirement. Since only pumping and transport energies increase with increasing total application, it is plausible that the energy requirement of the center pivot should increase at a greater rate than other systems.

The relationship between energy requirement and acreage irrigated, shown in Figures 20-28, indicates that changing acreage has little effect in most cases. For the solid set and permanent sprinkler systems, however, there appears to be a substantial increase in energy requirements with increasing acreage irrigated. The increase appears significant between 80 and 160 acres. The most probable cause for this increase is manufacturing energy for lateral lines. The systems on smaller acreages are able to operate satisfactorily with two inch lateral lines. But with increased acreage, the laterals become of sufficient length that friction loss in a two inch line becomes larger than the recommended level of 20 percent of the lateral inlet head. The only acceptable course of action for the system designer is to use laterals of larger diameter. Attempts to reduce flow rate in the laterals, and thereby reduce friction head loss, require the use of sprinkler nozzles of such sizes that the coefficient of application uniformity is less than satisfactory. The size of laterals must, therefore, increase in a similar manner in other types of systems. However, the excessively larger number of laterals in the solid set and permanent sprinkler systems results in a substantial increase in the energy requirements of these two systems, while no noticeable effect is observed in other types of systems.

VI. CONCLUSION

A computer model has been developed which simulates the total energy requirement to develop and operate various irrigation systems. The model simulates each system by modularizing its energy needs into four basic energy areas: manufacturing, installation, operation, and transportation. The model considers the total, non-renewable energy resources used in the form of fossil fuel.

This simulation model has exhibited that, for the cases considered, there is a fairly consistent energy consumption hierarchy among irrigation systems. Surface irrigation requires the least energy per acre of land irrigated, with drip, side roll, and hand move sprinkler systems following in order of increasing energy requirement. At lower application levels, center pivot, permanent, and solid set sprinkler systems follow in order, with center pivot requiring the most energy at the highest application levels considered. The surface irrigation system required no pumping energy, and all other energy expenditures were prorated over the expected system life of 25 years. Even with substantial energy costs for leveling, it was by far the most energy-conservative method. The drip irrigation system, though requiring a considerable amount of apparatus in the form of laterals and emitters, needed only moderate energy inputs due to the low pumping rate and pumping head necessary for operation. The side roll and hand move sprinkler systems required approximately the same level of energy inputs, as would be expected due to the similarity in their configurations. The permanent and solid set sprinkler systems, though quite similar, used substantially different amounts of energy. This difference was largely due to the materials used in each system. The permanent system used polyvinylchloride, which has a lower manufacturing energy and a more favorable friction coefficient. The center pivot sprinkler system occupied the upper portion of the energy spectrum, spanning the range of the solid set and permanent systems. (The size and number of laterals in the solid set and permanent systems appear to make these systems more susceptible to energy requirement increases with increases in irrigated acres.) The sizable amount of energy required for pumping by the center pivot system made it the most susceptible to increases in total application and consumptive use rate.

Another trend evident in the output related to mainline pipe economy. In the past, a rule of thumb generally used by systems designers stated that the most economical mainline size, in terms of operating cost, was one that produced approximately one foot of friction head loss per hundred feet of pipe. This energy analysis of systems seems to show that much larger pipelines produce the most energy-efficient systems. For the aluminum mainlines used in this model, a friction loss of approximately one foot per four hundred feet appeared to be the level at which the most energy-efficient system was found.

In conclusion, the model is a valuable tool, adaptable to a wide variety of operating situations. However, the validity of its results are dependent upon a few critical pieces of information. As a result, the operator of the model should exercise care in making comparisons between and drawing conclusions about irrigation system energy requirements. Currently, the results of this study will be of limited value to the designer of irrigation systems, whose major concern is still economic. As the cost of energy continues to rise, the economic and energy considerations of irrigation system design should become more and more closely aligned.

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APPENDIX A.

MODEL INPUT DATA TABLES

TABLE I. DIMENSIONS OF SYSTEM COMPONENTS.

Nominal Diameter (in.)	Pipe Weight (lb./ft.)				Coupler Weight (lb.)		
	Aluminum	Steel	PVC	Asbestos-Cement	Aluminum	Steel	Asbestos-Cement
Laterals							
1	--	1.24	0.16	--	--	1.00	--
2	0.36	2.67	0.52	--	2.1	1.75	--
3	0.54	4.10	1.13	--	2.7	3.00	--
4	0.73	5.53	1.87	--	3.3	4.00	--
5	0.94	6.96	2.86	--	4.7	5.00	--
Mainlines							
3	0.54	4.10	1.13	--	2.7	--	--
4	0.73	5.53	1.87	--	3.3	--	--
5	0.94	6.96	1.88	8.3	4.4	--	8.0
6	1.26	8.39	2.67	11.2	5.5	--	10.6
7	1.64	--	--	--	6.6	--	--
8	1.88	11.26	4.51	16.5	9.6	--	13.5
10	2.38	14.12	7.02	22.6	10.0	--	15.9
12	--	16.98	9.65	31.5	--	--	24.0
Side Roll Laterals							
4	1.05	--	--	--	5.4	--	--
5	1.42	--	--	--	7.4	--	--

TABLE II. MANUFACTURING ENERGY OF BASIC MATERIALS.

Material	Berry and Makino (1974)	Hannon (1974)	Rabitsch (1974)	Stuam (1975)	Steinhart and Steinhart (1974)	Eliot-Jones (1974)	Used in this study
	Kilowatt-hours/lb. (mega-joules/kg.)						
Steel	6.85 (54.37)	--	3.66 (29.05)	1.76 (13.97)	9.89 (78.49)	--	8.5 (67.46)
Aluminum	36.5 (289.68)	--	--	--	34.9 (276.98)	28.6 (226.98)	36.0 (285.71)
Brass	--	37.8 (300.0)	--	--	1.0 (7.94)	--	20.0 (158.72)
PVC	15.2 (120.63)	--	--	9.7 (76.98)	--	--	15.2 (120.63)
Poly-ethylene	20.2 (160.32)	--	--	--	0.70 (5.56)	--	20.0 (158.72)
Asbestos-Cement	--	--	--	1.6 (12.70)	--	--	1.6 (12.70)
Concrete	--	--	--	1.1 (8.73)	--	--	1.1 (8.73)

TABLE III. CONVERSION FACTORS FOR ENERGY UNITS (CHEMICAL RUBBER CO., 1963).

One Unit / Equals	Kilowatt-Hour (kwh.)	Mega-Joule (Mj.)	British Thermal Unit (b.t.u.)	Kilogram-Calorie (Kcal.)	Barrel of Oil (bbl.)	Ton of Coal (T.)
Ton of Coal (T.)	1.31×10^{4}	3.65×10^{-5}	3.85×10^{-8}	1.53×10^{-7}	2.23×10^{-1}	1.
Barrel of Oil (bbl.)	5.88×10^{-4}	1.63×10^{-4}	1.72×10^{-7}	6.84×10^{-7}	1.	4.48
Kilogram-Calorie (Kcal.)	8.60×10^{2}	2.39×10^{2}	2.52×10^{-1}	1.	1.46×10^{6}	6.55×10^{6}
British Thermal Unit (b.t.u.)	3.41×10^{3}	9.48×10^{2}	1.	3.97	5.80×10^{6}	2.6×10^{7}
Mega-Joule (Mj.)	3.6	1.	1.06×10^{-3}	4.18×10^{-3}	6.12×10^{3}	2.74×10^{4}
Kilowatt-Hour (kwh.)	1.	2.78×10^{-1}	2.93×10^{-4}	1.16×10^{-3}	1.70×10^{3}	7.62×10^{3}

APPENDIX B.

A COMPUTER MODEL TO SIMULATE FARM IRRIGATION SYSTEM ENERGY REQUIREMENTS

Program Listing and Documentation

Title: A Computer Model to Simulate Farm Irrigation System Energy Requirements

Authors: J. W. Wolfe, R. B. Wensink and M. A. Kizer

Installation: CDC 3300 at Oregon State University

Programming Language: Standard FORTRAN IV

Date Written: Fall, 1975

Remarks: This computer model simulates energy requirements for the following irrigation systems: hand move, center pivot, drip, side roll, solid set, surface and permanent systems. All major variables and inputs are defined at the beginning of each subroutine.

PROGRAM INPUT:

Data Files:

*XINSTEP - data for Hand Move Sprinkler System
*XINCENT - data for Central Pivot Sprinkler System
*XINDRIP - data for Trickle Irrigation System
*XINSIDE - data for Side Roll Sprinkler System
*XINSOLID - data for Solid Set Sprinkler System
*XINPERM - data for Permanent Sprinkler System

*MAINLNS - basic mainline dimensions
*LATERAL - basic lateral dimensions (diameter, lateral and coupler weight)

Inputs:

Type of system under consideration:

(1) Hand move sprinkler system
(2) Center pivot sprinkler system
(3) Trickle irrigation system
(4) Side roll sprinkler system
(5) Solid set sprinkler system
(6) Surface irrigation system
(7) Permanent sprinkler system

(1) Hand Move, input:
- (a) number of system laterals
- (b) diameter of laterals and mainline segments
- (c) diameter, flow rate and length of each mainline segment
- (d) whether or not mainline or laterals are buried.

(2) Center Pivot, input:
- (a) whether or not mainline is buried.

(3) Trickle Irrigation, input:
- (a) number of emitters - length, flow and pressure
- (b) emitter type - dripeze or microtube
- (c) whether or not mainline and laterals are buried.

(4) Side Roll, input:
- (a) number of system laterals
- (b) diameter of laterals and mainline segments
- (c) diameter, flow rate and length of each mainline segment
- (d) whether or not mainline or laterals are buried.

(5 or 7) Solid Set or Permanent Sprinklers, input:
- (a) number of system laterals
- (b) diameter of laterals and mainline segments
- (c) diameter, flow rate and length of each mainline segment
- (d) whether or not mainline or laterals are buried.

(6) Surface Irrigation system, input:

   (a) tractor used in field leveling

      (1) D7 and 10 cubic yard carryall

      (2) D8 and 14 cubic yard carryall

      (3) D9 and 20 cubic yard carryall

   (b) irrigation type

      (1) furrows

      (2) corrugations

   (c) whether or not pumping is required to irrigate

   (d) static lift, source to field

   (e) head ditch type

      (1) unlined

      (2) concrete lined

      (3) gated lined

   (f) diameter of gated pipe

   (g) control type used

      (1) siphon tubes

      (2) earth turnouts

      (3) concrete turnouts

Outputs:

(1) Prelininary results

   mainline friction loss, installation energy, etc.

(2) Final results

   (a) Total Seasonal Energy

   (b) Seasonal Energy per Acre

   (c) Energy per Acre-Inch

```
      PROGRAM IRRIGATE
C
C
C
C
C
C     MODEL TO SIMULATE IRRIGATION SYSTEM ENERGY REQUIREMENTS
C
C
C
C     THIS MODEL SIMULATES TOTAL ENERGY REQUIREMENTS FOR:
C
C          2  CENTER PIVOT SPRINKLER SYSTEMS
C          3  TRICKLE IRRIGATION SYSTEMS
C          4  SIDE ROLL SPRINKLER SYSTEMS
C          5  SOLID SET SPRINKLER SYSTEMS
C          6  SURFACE IRRIGATION SYSTEMS
C          7  PERMANENT SPRINKLER SYSTEMS
C
C
C
C     ALL VARIABLES ARE DEFINED AT THE BEGINNING OF
C     SUBROUTINE STEPMAIN
C
C     ANY NEW VARIABLE NAMES OR CHANGES IN VARIABLE NAMES
C     FOR SUBSEQUENT SUBROUTINES ARE GIVEN AT THE BEGINNING
C     OF THE SUBROUTINE IN WHICH THE INPUT DATA IS READ FOR
C     EACH IRRIGATION SYSTEM TYPE.
C
C
C
C
C
C
```

```
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,
     3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,
     5ELMFT,ENINST,EPPMFT,TENPS,TEMMFT,ETTRP,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
      DATA(VNAME=≠*XINSTEP≠)
6001  FORMAT(8F10.2)
6002  FORMAT(3I2,2I3)
      CALL EQUIP(21,VNAME)
C
C     READ BASIC INPUT DATA
      READ(21,6002) IPTY,MLTY,MMTY
      READ(21,6001) SPOH,CHWM,CHWL,STL,ELEVDF,HFSL,HFMISC
      READ(21,6001) TNA,DNA,XLNLT,XLNMN,RIHT
      READ(21,6001) EFPP,EFGP,EFIR,EFMO
      READ(21,6001) FREQ,HPD,TRWT,ACRE,WIDE
      CALL UNEQUIP(21)
      CALL OPRATE1
      CALL MANFCT1
      CALL TRNSPRT1
      CALL INSTALL1
C
C     PRINT TOTAL ENERGY DATA FOR SYSTEM
      TOTSEN=TENPS+ETTRP+(TEMMFT+ELMFT+ENINST)/20.
     1+EPPMFT/15.+ENSPMFT/10.
      WRITE(61,6100)TOTSEN
6100  FORMAT(5X,≠TOTAL SEASONAL ENERGY=≠,F20.2,≠ KWH≠)
      SENPA=TOTSEN/ACRE
      WRITE(61,6131)SENPA
6131  FORMAT(5X,≠SEASONAL ENERGY PER ACRE=≠,F15.2,≠ KWH≠)
      ENPAI=SENPA/TNA
      WRITE(61,6196)ENPAI
6196  FORMAT(5X,≠ENERGY PER ACRE-INCH=≠,F10.2,≠ KWH/ACRE-INCH≠)
      RETURN
      END


      SUBROUTINE STEPMAIN
C
C     HAND MOVE SPRINKLER SYSTEM ENERGY REQUIREMENTS
C
C     SPOH = SPRINKLER PRESSURE (PSI)
C     HFL = LATERAL FRICTION LOSS (FT)
C     HFM = MAINLINE FRICTION LOSS (FT)
C     STL = STATIC LIFT (FT)
C     ELEVDF = ELEVATION DIFFERENCE PUMP-TO-FIELD (FT)
C     HFSL = SUCTION LINE FRICTION LOSS (FT)
C     HFMISC = MISCELLANEOUS FRICTION LOSSES (FT)
C     SPRNO = NUMBER OF SPRINKLERS PER LATERAL
C     QSPR = SPRINKLER DISCHARGE (GAL/MIN)
C     EFPP = PUMP EFFIENCY
```

```
C      EFGP = GENERATING PLANT EFFIENCY
C      IPTY = POWER UNIT TYPE
C               0 = ELECTRIC MOTOR
C               1 = INTERNAL COMBUSTION ENGINE
C      THHP = FUEL POTENTIAL (HP)
C      XNLTS = NUMBER OF LATERAL LINES
C      XLNLT = LENGTH OF LATERAL PIPE SECTION (FT)
C      IDLT = LATERAL LINE DIAMETER (IN)
C      EFMO = MOTOR EFFIENCY
C      XLNMN = LENGTH OF MAINLINE PIPE SECTION (FT)
C      IDMN = DIAMETER OF MAINLINE (IN)
C      RIHT = HEIGHT OF RISER PIPE (FT)
C      CHWM = HAZEN-WILLIAMS COEFFICIENT, MAINLINE
C      CHWL = HAZEN-WILLIAMS COEFFICIENT, LATERAL
C      BHP = REQUIRED BRAKE HORSEPOWER OF MOTOR (HP)
C      MLTY = TYPE OF LATERAL MATERIAL
C      MMTY = TYPE OF MAINLINE MATERIAL
C               1 = STEEL          3 = PVC
C               2 = ALUMINUM       4 = TRANSITE
C      SPOHF = SPRINKLER PRESSURE HEAD (FT)
C      TRWT = WEIGHT OF PIPE TRAILER (LB)
C      MNPO = MAINLINE LOCATION
C      ILTPO = LATERAL LINE LOCATION
C      XNIPS = NUMBER OF IRRIGATION CYCLES PER SEASON
C      ACRE = FIELD AREA (ACRES)
C      DMNF = MAINLINE DIAMETER (FT)
C      DLTF = LATERAL LINE DIAMETER (FT)
C      TLNLT = TOTAL LENGTH OF LATERAL LINE (FT)
C      QM = FLOW RATE IN MAINLINE SEGMENT (GAL/MIN)
C      XLM = LENGTH OF MAINLINE SEGMENT (FT)
C      IDM = DIAMETER OF MAINLINE SEGMENT (IN)
C      NMS = NUMBER OF MAINLINE SEGMENTS
C      HPD = HOURS OF SYSTEM OPERATION PER DAY (HR)
C      TNA = SEASONAL APPLICATION (IN)
C      FREQ = FREQUENCY OF IRRIGATION (DAYS/IRRIGATION)
C      EFIR = IRRIGATION EFFIENCY
C      WIDE = NARROW DIMENSION OF FIELD (FT)
C      NIPS = NUMBER OF IRRIGATION CYCLES PER SEASON (FIXED)
C      ELMFT = ENERGY TO MANUFACTURE LATERAL LINES (KWH)
C      ENINST = ENERGY FOR INSTALLATION (KWH)
C      EPPMFT = ENERGY TO MANUFACTURE PUMPING PLANT (KWH)
C      TENPS = TOTAL PUMPING ENERGY PER SEASON (KWH)
C      TEMMFT = ENERGY TO MANUFACTURE MAINLINE (KWH)
C      ETTRP = ENERGY FOR TRANSPORT (KWH)
C      ENSPMFT = ENERGY TO MANUFACTURE SPRINKLERS (KWH)
C      NOSPR = NUMBER OF SPRINKLERS PER LATERAL LINE (FIXED)
C      SENPA = SEASONAL ENERGY PER ACRE (KWH/ACRE)
C      ENPAI = SEASONAL ENERGY PER ACRE INCH (KWH/ACRE-IN)
C      DNA = NET IRRIGATION REQUIREMENT (IN/IRRIGATION)
C      PUMPHP(I) = DESIGN PUMP HORSEPOWER (HP)
C      ISYSTY = IRRIGATION TYPE
C      QLT = LATERAL PIPE LINE FLOW RATE (GAL/MIN)
C      QLTF = LATERAL PIPE LINE FLOW RATE (CFS)
C      QMF = MAINLINE FLOW RATE (CFS)
```

```
C      HFP = FRICTION LOSS IN PARTIAL MAINLINE SEGMENT (FT)
C      QPUMP = PUMP CAPICITY (GAL/MIN)
C      TTOT = TOTAL SEASONAL OPERATING TIME (HR)
C      MD = MAINLINE DIAMETER FROM DATA FILE (IN)
C      AMW = ALUMINUM MAILINE WEIGHT (LB/FT)
C      AMCW = ALUMINUM MAINLINE COUPLER WEIGHT (LB)
C      SMW = STEEL MAINLINE WEIGHT (LB/FT)
C      ABMW = TRANSITE MAINLINE WEIGHT (LB/FT)
C      ABMCW = TANSITE MAINLINE COUPLER WEIGHT (LB)
C      PVMN = PVC MAINLINE WEIGHT (LB/FT)
C      ILD = LATERAL DIAMETER FROM DATA FILE (IN)
C      ALW = ALUMINUM LATERAL WEIGHT (LB/FT)
C      ALCW = ALUMINUM LATERAL COUPLER WEIGHT (LB)
C      SLW = STEEL LATERAL WEIGHT (LB/FT)
C      SLCW = STEEL LATERAL COUPLER WEIGHT (LB)
C      PVLW = PVC LATERAL WEIGHT (LB/FT)
C
       COMMON/TAG/ISYSTY
       DATA(NYES=≠YES ≠)
C
C      SELECTION OF SYSTEM TO SIMULATE
 100   WRITE(61,6191)
 6191 FORMAT(5X,≠CHOOSE THE TYPE OF SYSTEM YOU WISH TO≠
     1≠ CONSIDER:≠,/1X,≠ 1 : HANDMOVE SPRINKLER≠,/1X,
     2≠ 2 : CENTER PIVOT≠,/1X,≠ 3 : DRIP IRRIGATION≠,/1X,
     3≠ 4 : SIDE ROLL SPRINKLER≠,/1X,≠ 5 : SOLID SET≠
     4≠ SPRINKLER≠,/1X,≠ 6 : SURFACE (FURROW ≤ CORRUGATE)≠
     5≠ IRRIGATION≠,/1X,≠ 7 : PERMANENT SPRINKLER≠,/1X,
     6≠       ENTER THE NUMBER OF THE SYSTEM DESIRED.≠)
       READ(60,6091)ISYSTY
 6091 FORMAT(I1)
       GO TO (101,102,103,104,105,106,107)ISYSTY
 101   CALL STEPMAIN
       GO TO 108
 102   CALL CIRCIRR
       GO TO 108
 103   CALL TRICKLE
       GO TO 108
 104   CALL SIDEMOVE
       GO TO 108
 105   CALL SOLIDSET
       GO TO 108
 106   CALL FURROW
       GO TO 108
 107   CALL SOLIDSET
 108   CONTINUE
       WRITE(61,6192)
 6192 FORMAT(5X,≠DO YOU WISH TO CONSIDER ANOTHER SYSTEM^≠
     1≠ (YES-NO)≠)
       READ(60,6092)NRUN
 6092 FORMAT(R4)
       IF(NRUN.EQ.NYES)GO TO 100
       STOP
       END
```

```
      SUBROUTINE OPRATE1
C
C     CALCULATE PUMPING ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,
     3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,
     5ELMFT,ENINST,EPPMFT,TENPS,TEMMFT,ETTRP,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
C
C     CALCULATION OF PUMPING RATE
      TLNLT=WIDE/2.
      SPRNO=TLNLT/XLNLT
      NOSPR=IFIX(SPRNO)
      QPUMP=ACRE*DNA*453./(FREQ*HPD*EFIR)
      WRITE(61,6187)QPUMP
6187  FORMAT(5X,≠QPUMP=≠,F10.2,≠ GPM≠)
      WRITE(61,618)
618   FORMAT(5X,≠ENTER NUMBER OF SYSTEM LATERALS. XX.≠)
C
C     READ NUMBER OF LATERALS IN THE SYSTEM
      READ(60,608)XNLTS
608   FORMAT(F10.2)
      QLT=QPUMP/XNLTS
      QSPR=QLT/NOSPR
      DNOZ=(QSPR/(28.94*SPOH**.5))**.5
      XNIPS=(TNA/DNA)+.99
      NIPS=IFIX(XNIPS)
      TTOT=NIPS*FREQ*HPD
      QLTF=QLT*.00223
      WRITE(61,6195)QLT
6195  FORMAT(5X,≠QLATERAL=≠,F7.2,≠ GPM≠)
      WRITE(61,611)
611   FORMAT(5X,≠ENTER NUMBER OF MAIN STEPS, LATERAL SIZE,≠,
     1/1X,≠ UNDER -1,2-RESPECTIVELY≠,
     2/1X,≠123≠)
C
C     READ DIAMETER OF LATERALS AND NUMBER OF MAINLINE SEGMENTS
      READ(60,601) NMS,IDLT
601   FORMAT(2I1)
      WRITE(61,6188)
6188  FORMAT(1X,≠DIAMETER-FLOW RATE-LENGTH≠)
C
C     READ DIAMETER, FLOW RATE, AND LENGTH OF EACH
C     MAINLINE SEGMENT.
      READ(60,6021)(IDM(I),QM(I),XLM(I),I=1,NMS)
6021  FORMAT(I2,F18.2,F10.2)
      DLTF=IDLT/12.0
      SPOHF=SPOH*2.307
      HFM=0.0
```

```
C      CALCULATE FRICTION HEAD IN MAINLINE
       DO 500 I=1,NMS
       DMNF=IDM(I)/12.0
       QMF=QM(I)/448.83
       HFP=((QMF*XLM(I)**.54)/(((3.14*DMNF**2)/4)*
      1((DMNF/4)**.63)*(1.318*CHWM)))**1.85
       WRITE(61,6181)I,HFP
6181   FORMAT(5X,≠HFM(INCREMENTAL)≠,I2,≠ =≠,F10.2)
       HFM=HFM+HFP
500    CONTINUE
C
C      CALCULATE FRICTION HEAD IN LATERAL
       HFL=(((QLTF*TLNLT**.54)/(((3.14*DLTF**2)/4)*((DLTF/4)
      1**.63)*(1.318*CHWL)))**1.85)*(.351+(.5/SPRNO)+
      2SQRT(.1417/SPRNO**2))
C
C      CALCULATE TOTAL DYNAMIC HEAD
       TDH=SPOHF+HFL+HFM+STL+ELEVDF+HFSL+HFMISC+RIHT
       WHP=QPUMP*TDH/3960.
       BHP=WHP/EFPP
C
C      CALCULATE TOTAL POWER AND ENERGY REQUIREMENTS FOR PUMPING
       IF(IPTY.GT.0) GO TO 100
       THHP=BHP/(EFGP*EFMO)
       GO TO 101
100    THHP=BHP/EFMO
101    TENPS=TTOT*THHP*.7457
C
C      WRITE RESULTS
       WRITE(61,6101) THHP
6101   FORMAT(10X,≠THE THERMAL HORSEPOWER=≠,F10.2)
       WRITE(61,6201) HFM,HFL,TDH
6201   FORMAT(5X,≠HFM=≠,F10.2,/5X,≠HFL=≠,F10.2,/5X,
      1≠TDH=≠,F10.2)
       WRITE(61,6189)DNOZ
6189   FORMAT(5X,≠SPRINKLER NOZZLE DIAMETER=≠,F8.6,≠ IN.≠)
       WRITE(61,6190)TENPS
6190   FORMAT(5X,≠SEASONAL PUMPING ENERGY=≠,F12.2,≠ KWH≠)
       RETURN
       END
```

```
       SUBROUTINE MANFCT1
C
C      CALCULATE MANUFACTURING ENERGY
C
       COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
      1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
      2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,
      3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
      4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,
      5ELMFT,ENINST,EPPMFT,TENPS,TEMMFT,ETTRP,ENSPMFT,NOSPR
       DIMENSION QM(10),XLM(10),IDM(10)
       DIMENSION MD(9),AMW(9),AMCW(9),SMW(9),ABMW(9),ABMCW(9)
       DIMENSION PVMW(9),PUMPHP(20)
```

```
      DIMENSION ILD(5),ALW(5),ALCW(5),SLW(5),SLCW(5),PVLW(5)
      DATA(XNAME=≠*MAINLNS≠)
      DATA(YNAME=≠*LATERAL≠)
      DATA(PUMPHP=0.75,1.0,1.5,2.0,3.0,5.0,7.5,10.0,15.0,
     120.0,25.0,30.0,40.0,50.0,60.0,75.0,100.0,125.0,
     2150.0,200.0)
      CALL EQUIP(12,XNAME)
C
C     READ BASIC MAINLINE DIMENSIONS
      READ(12,6012)(MD(J),AMW(J),AMCW(J),SMW(J),ABMW(J),
     1ABMCW(J),PVMW(J),J=1,8)
6012  FORMAT(I3,6F6.2)
      CALL UNEQUIP(12)
      TEMMFT=0.0
C
C     CALCULATE TOTAL WEIGHT OF MAINLINE MATERIAL AND ENERGY
C     FOR MANUFACTURE.
      DO 99 I=1,NMS
      DO 69 J=1,8
      IF(IDM(I).EQ.MD(J)) GO TO 60
69    CONTINUE
60    GO TO(201,202,203,204),MMTY
201   TMNWT=XLM(I)/XLNMN*(XLNMN*SMW(J))
      EMMFT=TMNWT*8.5
      GO TO 210
202   TMNWT=XLM(I)/XLNMN*(XLNMN*AMW(J)+AMCW(J))
      EMMFT=TMNWT*36.
      GO TO 210
203   TMNWT=XLM(I)/XLNMN*(XLNMN*PVMW(J))
      EMMFT=TMNWT*15.2
      GO TO 210
204   TMNWT=XLM(I)/XLNMN*(XLNMN*ABMW(J)+ABMCW(J))
      EMMFT=TMNWT*8.0
210   TEMMFT=TEMMFT+EMMFT
99    CONTINUE
C
C     WRITE MAINLINE MANUFACTURING ENERGY
      WRITE(61,6112)TEMMFT
6112  FORMAT(5X,≠ENERGY TO MANUFACTURE MAINLINES=≠,F10.2,
     1≠ KILOWATT-HOURS≠)
      CALL EQUIP(13,YNAME)
C
C     READ BASIC LATERAL DIMENSIONS
      READ(13,6013)(ILD(I),ALW(I),ALCW(I),SLW(I),SLCW(I),
     1PVLW(I),I=1,5)
6013  FORMAT(I3,5F6.2)
C
C     CALCULATE TOTAL WEIGHT OF LATERAL MATERIAL AND ENERGY
C     FOR MANUFACTURE.
      DO 50 I=1,5
      IF(IDLT.EQ.ILD(I)) GO TO 59
50    CONTINUE
59    GO TO(301,302,303),MLTY
301   RIWT=(RIHT*0.4)+0.2
```

```
      TLATWT=XNLTS*SPRNO*(XLNLT*SLW(I)+SLCW(I)+RIWT)
      ELMFT=TLATWT*8.5
      GO TO 310
302   RIWT=RIHT*0.6
      TLATWT= XNLTS*SPRNO*(XLNLT*ALW(I)+ALCW(I)+RIWT)
      ELMFT=TLATWT*36.
      GO TO 310
303   RIWT=RIHT*0.15
      TLATWT=XNLTS*SPRNO*(XLNLT*PVLW(I)+RIWT)
      ELMFT=TLATWT*15.2
310   CONTINUE
      CALL UNEQUIP(13)
C
C     WRITE LATERAL MANUFACTURING ENERGY
      WRITE(61,6113)ELMFT
6113  FORMAT(5X,≠ENERGY TO MANUFACTURE LATERALS=≠,F10.2,
     1≠ KILOWATT-HOURS≠)
C
C     CALCULATE MANUFACTURING ENERGY FOR PUMPING UNIT
      DO 70 I=1,20
      IF(BHP.LE.PUMPHP(I)) GO TO 40
70    CONTINUE
40    DBHP=PUMPHP(I)
      WRITE(61,6121)DBHP
6121  FORMAT(5X,≠DESIGN POWER UNIT CAPACITY=≠,F7.2,≠ HP≠)
      EPPMFT=DBHP*1163.0
      WRITE(61,6111)EPPMFT
6111  FORMAT(5X,≠ENERGY TO MANUFACTURE PUMPING PLANT=≠,
     1F10.2,≠ KILOWATT-HOURS≠)
C
C     CALCULATE MANUFACTURING ENERGY FOR SPRINKLERS
      WTSPR=NOSPR*XNLTS*1.1
      ENSPMFT=WTSPR*19.77
      WRITE(61,6117)ENSPMFT
6117  FORMAT(5X,≠ENERGY TO MANUFACTURE SPRINKLERS=≠,F12.2,
     1≠ KWH≠)
      RETURN
      END
```

```
      SUBROUTINE TRNSPRT1
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,
     3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,
     5ELMFT,ENINST,EPPMFT,TENPS,TEMMFT,ETTRP,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
```

```
C      CALCULATE ENERGY FOR TRANSPORTING PIPES
       ETRMFT=TRWT*8.5/20.
       EFTRP=6.*NIPS*39.41
       ETTRP=ETRMFT+EFTRP
       WRITE(61,6116)ETTRP
6116   FORMAT(5X,≠ENERGY FOR TRANSPORT=≠,F10.2,
      1≠ KILOWATT-HOURS PER SEASON≠)
       RETURN
       END


       SUBROUTINE INSTALL1
       COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
      1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
      2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,
      3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
      4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,
      5ELMFT,ENINST,EPPMFT,TENPS,TEMMFT,ETTRP,ENSPMFT,NOSPR
       DIMENSION QM(10),XLM(10),IDM(10)
       DATA(IYES=≠YES ≠)
C
C      CALCULATE ANY INSTALLATION ENERGY FOR BURYING PIPELINES
       WRITE(61,6162)
6162   FORMAT(5X,≠IS MAINLINE BURIED^≠)
       READ(60,6062)MNPO
6062   FORMAT(R4)
       WRITE(61,6163)
6163   FORMAT(5X,≠ARE LATERALS BURIED^≠)
       READ(60,6063)ILTPO
6063   FORMAT(R4)
       IF(MNPO.EQ.IYES)GO TO 600
       IF(ILTPO.EQ.IYES)GO TO 601
       ENINST=0.00
       WRITE(61,6161)
6161   FORMAT(5X,≠INSTALLATION ENERGY IS NEGLIGIBLE.≠)
       GO TO 900
600    IF(ILTPO.EQ.IYES)GO TO 701
C
C      CALULATE VOLUME OF EXCAVATION AND ENERGY REQUIREMENT
       ENINST=0.0
       DO 650 I=1,NMS
       DMNF=IDM(I)/12.0
       EMINST=XLM(I)*(2.+DMNF)*(.33+DMNF)*.3
650    ENINST=ENINST+EMINST
       GO TO 800
601    ENINST=TLNLT*(2.+DLTF)*(.33+DLTF)*.3
       GO TO 800
701    ENINST=TLNLT*(2.+DLTF)*(.33+DLTF)+TXLNMN*(2.+DMNF)*
      1(.33+DMNF)*.3
800    WRITE(61,6164)ENINST
6164   FORMAT(5X,≠INSTALLATION ENERGY=≠,F10.2,≠ KILOWATT-HOURS≠)
900    RETURN
       END
```

```
      SUBROUTINE CIRCIRR
C
C     CENTER PIVOT SPRINKLER SYSTEM ENERGY REQUIREMENTS
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,EFMO,
     1EFPP,EFGP,IPTY,THHP,IDLT,XNMNS,NIPS,FREQ,EFIR,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,BHP,MLTY,MMTY,TNA,DNA,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,XNTOW,
     4XENPT,EMMFT,ELMFT,EPPMFT,TETRPT,ENINST
C
C     NEW VARIABLES DEFINED FOR SUBROUTINE CIRCIRR
C
C     XNMS = NUMBER OF MAINLINE SECTIONS
C     XNTOW = NUMBER OF LATERAL SUPPORT TOWERS
C     TETRPT = TRANSPORT ENERGY (KWH)
C     XENPT = SEASONAL PUMPING ENERGY (KWH)
C     FREQ = ROTATION TIME FOR SYSTEM (HR)
C     QGPM = PUMPING RATE (GPM)
C
      DATA(WNAME=≠*XINCENT≠)
6001  FORMAT(8F10.2)
6002  FORMAT(3I2,2I3)
      CALL EQUIP(41,WNAME)
C
C     READ BASIC INPUT DATA
      READ(41,6002) IPTY,MLTY,MMTY,IDLT,IDMN
      READ(41,6001) SPOH,CHWM,CHWL,STL,ELEVDF,HFSL,HFMISC
      READ(41,6001) TNA,DNA,TLNLT,XLNMN,RIHT
      READ(41,6001) EFPP,EFGP,EFIR,EFMO,XNMNS
      READ(41,6001) FREQ,ACRE,XNTOW
      CALL UNEQUIP(41)
      CALL OPRATE2
      CALL MANFCT2
      CALL TRNSPRT2
      CALL INSTALL2
C
C     CALCULATE AND WRITE SEASONAL ENERGY REQUIREMENTS
      TOTSEN=XENPT+TETRPT+(EMMFT+ELMFT+EPPMFT+ENINST)/20.
       WRITE(61,6100)TOTSEN
6100  FORMAT(5X,≠TOTAL SEASONAL ENERGY=≠,F20.2,≠ KWH≠)
      SENPA=TOTSEN/ACRE
      WRITE(61,6110)SENPA
6110  FORMAT(5X,≠SEASONAL ENERGY PER ACRE=≠,F20.2,≠ KWH≠)
      ENPAI=SENPA/TNA
      WRITE(61,6190)ENPAI
6190  FORMAT(5X,≠ENERGY PER ACRE-INCH=≠,F10.2,≠ KWH/ACRE-INCH≠)
      RETURN
      END
```

```
      SUBROUTINE OPRATE2
C
C     CALCULATE PUMPING ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,EFMO,
     1EFPP,EFGP,IPTY,THHP,IDLT,XNMNS,NIPS,FREQ,EFIR,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,BHP,MLTY,MMTY,TNA,DNA,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,XNTOW,
     4XENPT,EMMFT,ELMFT,EPPMFT,TETRPT,ENINST
C
C     CALCULATE PUMPING RATE
      QGPM=ACRE*DNA*453./(FREQ*EFIR)
      XNIPS=TNA/DNA+.99
      NIPS=IFIX(XNIPS)
      Q=QGPM*0.002228
      TTOT=NIPS*FREQ
      DMNF=IDMN/12.0
      DLTF=IDLT/12.0
      SPOHF=SPOH*2.307
      TXLNMN=XLNMN*XNMNS
C
C     CALCULATE TOTAL HEAD REQUIREMENTS
      HFM=((Q*TXLNMN**.54)/(((3.14*DMNF**2)/4)*
     1((DMNF/4)**.63)*(1.318*CHWM)))**1.85
      HFL=(((Q*TLNLT**.54)/(((3.14*.5521**2)/4)*((.5521/4)
     1**.63)*(1.318*CHWL)))**1.85)*.5333
      TDH=SPOHF+HFL+HFM+STL+ELEVDF+HFSL+HFMISC+RIHT
C
C     CALCULATE POWER REQUIREMENT AND PUMPING ENERGY
      WHP=Q*TDH/8.81
      BHP=WHP/EFPP
      IF(IPTY.GT.0) GO TO 100
      THHP=BHP/(EFGP*EFMO)
      GO TO 101
100   THHP=BHP/EFMO
101   XENPT=TTOT*THHP*(.7457)
      WRITE(61,6101) THHP
6101  FORMAT(10X,≠THE THERMAL HORSEPOWER=≠,F10.2)
      WRITE(61,6201) HFM,HFL,TDH
6201  FORMAT(5X,≠HFM=≠,F10.2,/5X,≠HFL=≠,F10.2,/5X,
     1≠TDH=≠,F10.2)
      WRITE(61,6221) XENPT
6221  FORMAT(5X,≠TOTAL PUMPING ENERGY PER SEASON=≠,F15.2,
     1≠ KWH≠)
      WRITE(61,6227)TTOT
6227  FORMAT(5X,F10.2)
      WRITE(61,6222)QGPM
6222  FORMAT(5X,≠PUMP DELIVERY CAPACITY=≠,F10.2,≠ GPM≠)
      WRITE(61,6231)NIPS
6231  FORMAT(5X,≠NUMBER OF IRRIGATIONS PER SEASON=≠,I4,
     1≠ CYCLES≠)
      RETURN
      END
```

```
      SUBROUTINE MANFCT2
C
C     CALCULATE MANUFACTURING ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,EFMO,
     1EFPP,EFGP,IPTY,THHP,IDLT,XNMNS,NIPS,FREQ,EFIR,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,BHP,MLTY,MMTY,TNA,DNA,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,XNTOW,
     4XENPT,EMMFT,ELMFT,EPPMFT,TETRPT,ENINST
      DIMENSION MD(9),AMW(9),AMCW(9),SMW(9),ABMW(9),ABMCW(9)
      DIMENSION PVMW(9),PUMPHP(20)
      DIMENSION ILD(5),ALW(5),ALCW(5),SLW(5),SLCW(5),PVLW(5)
      DATA(XNAME=≠*MAINLNS≠)
      DATA(PUMPHP=0.75,1.0,1.5,2.0,3.0,5.0,7.5,10.0,15.0,
     120.0,25.0,30.0,40.0,50.0,60.0,75.0,100.0,125.0,
     2150.0,200.0)
      CALL EQUIP(12,XNAME)
C
C     READ BASIC MAINLINE DIMENSIONS
      READ(12,6012)(MD(I),AMW(I),AMCW(I),SMW(I),ABMW(I),
     1ABMCW(I),PVMW(I),I=1,8)
6012  FORMAT(I3,6F6.2)
      CALL UNEQUIP(12)
      DO 69 I=1,8
      IF(IDMN.EQ.MD(I)) GO TO 60
69    CONTINUE
60    GO TO(201,202,203,204),MMTY
C
C     CALCULATE MAINLINE MANUFACTURING ENERGY
201   TMNWT=XNMNS*(XLNMN*SMW(I))
      EMMFT=TMNWT*8.5
      GO TO 210
202   TMNWT=XNMNS*(XLNMN*AMW(I)+AMCW(I))
      EMMFT=TMNWT*36.
      GO TO 210
203   TMNWT=XNMNS*(XLNMN*PVMW(I))
      EMMFT=TMNWT*15.2
      GO TO 210
204   TMNWT=XNMNS*(XLNMN*ABMW(I)+ABMCW(I))
      EMMFT=TMNWT*8.0
210   WRITE(61,6112)EMMFT
6112  FORMAT(5X,≠ENERGY TO MANUFACTURE MAINLINES=≠,F10.2,
     1≠ KILOWATT-HOURS≠)
      WRITE(61,4)I
4     FORMAT(5X,≠I=≠,I2)
C
C     CALCULATE MANUFACTURING ENERGY FOR LATERAL
      TLTWT=5000.+3000.*XNTOW
      ELMFT=TLTWT*8.5
      WRITE(61,6113)ELMFT
6113  FORMAT(5X,≠ENERGY TO MANUFACTURE ROTATING LATERAL=≠,
     1F10.2,≠ KWH≠)
```

```
C     CALCULATE MANUFACTURING ENERGY FOR PUMP UNIT
      DO 70 I=1,20
      IF(BHP.LE.PUMPHP(I)) GO TO 40
70    CONTINUE
40    DBHP=PUMPHP(I)
      WRITE(61,6121)DBHP
6121  FORMAT(5X,≠DESIGN POWER UNIT CAPACITY=≠,F7.2,≠ HP≠)
      EPPMFT=DBHP*1163.0
      WRITE(61,6111)EPPMFT
6111  FORMAT(5X,≠ENERGY TO MANUFACTURE PUMPING PLANT=≠,
     1F10.2,≠ KILOWATT-HOURS≠)
      RETURN
      END


      SUBROUTINE TRNSPRT2
C
C     CALCULATE TRANSPORT ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,EFMO,
     1EFPP,EFGP,IPTY,THHP,IDLT,XNMNS,NIPS,FREQ,EFIR,
     2XLNMN,IOMN,RIHT,CHWM,CHWL,BHP,MLTY,MMTY,TNA,DNA,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,XNTOW,
     4XENPT,EMMFT,ELMFT,EPPMFT,TETRPT,ENINST
      NTOW=IFIX(XNTOW)
      TIME=0.0
      DO 78 I=1,NTOW
      PTIME=2.*I
78    TIME=TIME+PTIME
      ENTRPT=0.828*TIME
      TETRPT=ENTRPT*NIPS
      WRITE(61,6144)TETRPT
6144  FORMAT(5X,≠TRANSPORT ENERGY=≠,F10.2,≠ KILOWATT-HOURS≠
     1≠ PER SEASON≠)
      RETURN
      END


      SUBROUTINE INSTALL2
C
C     CALCULATE ANY INSTALLATION ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,EFMO,
     1EFPP,EFGP,IPTY,THHP,IDLT,XNMNS,NIPS,FREQ,EFIR,
     2XLNMN,IOMN,RIHT,CHWM,CHWL,BHP,MLTY,MMTY,TNA,DNA,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,XNTOW,
     4XENPT,EMMFT,ELMFT,EPPMFT,TETRPT,ENINST
```

```
      DATA(IYES=≠YES ≠)
      WRITE(61,6162)
 6162 FORMAT(5X,≠IS MAINLINE BURIED^≠)
      READ(60,6062)MNPO
 6062 FORMAT(R4)
      IF(MNPO.EQ.IYES)GO TO 600
      ENINST=0.00
      WRITE(61,6161)
 6161 FORMAT(5X,≠INSTALLATION ENERGY IS NEGLIGIBLE.≠)
      GO TO 900
C
C     CALCULATE VOLUME OF EXCAVATION AND ENERGY REQUIREMENT
600   ENINST=TXLNMN*(2.+DMNF)*(.33+DMNF)*.3
      WRITE(61,6164)ENINST
 6164 FORMAT(5X,≠INSTALLATION ENERGY=≠,F10.2,≠ KILOWATT-HOURS≠)
900   RETURN
      END




      SUBROUTINE TRICKLE
C
C     TRICKLE IRRIGATION SYSTEM ENERGY REQUIREMENTS
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,NOPEM,
     1EMLN,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,HFSM,IDSM,EFMO,
     2XLNMN,IDMN,CHWM,CHWL,XLNSM,BHP,MLTY,MMTY,ROW,PLT,TLSM,
     3SPOHF,TLNMN,MNPO,ILTPO,DSMF,ACRE,DMF,DLTF,TXLNMN,TLNLT,
     4DM,XLM,IDM,NMS,HPD,DNA,TNA,EMGPH,EFIR,WIDE,NIPS,XLEN,ANLTS
     5,TENPS,ETTRP,ESMMFT,EMMFT,ELMFT,ENINST,EPPMFT,ENEMFT
C
C     NEW VARIABLES DEFINED FOR SUBROUTINE TRICKLE:
C     NOPEM = EMITTERS PER PLANT
C     EMLN = LENGTH OF MICRO TUBE EMITTER (FT)
C     XLNSM = LENGTH OF SUBMAINLINE PIPE SECTIONS (FT)
C     ROW = SPACING OF PLANT ROWS (FT)
C     PLT = SPACING OF PLANTS IN ROW (FT)
C     TLSM = LENGTH OF SUBMAINLINE (FT)
C     DSMF = DIAMETER OF SUBMAINLINE (FT)
C     IDSM = DIAMETER OF SUBMAINLINE (IN)
C     DNA = DAILY APPLICATION (IN/DAY)
C     XLEN = LONG DIMENSION OF FIELD (FT)
C     EMGPH = EMITTER DISCHARGE CAPACITY (GAL/HR)
C     ENSMMFT = ENERGY TO MANUFACTURE SUBMAINLINE (KWH)
C
      DIMENSION DM(10),XLM(10),IDM(10)
      DATA(UNAME=≠*XINDRIP≠)
 6001 FORMAT(8F10.2)
 6002 FORMAT(3I2,3I3)
      CALL EQUIP(1,UNAME)
```

```
C       READ BASIC INPUT DATA
        READ(1,6002) IPTY,MLTY,MMTY,IDLT,IDMN,IDSM
        READ(1,6001) CHWM,CHWL,STL,ELEVDF,HFSL,HFMISC
        READ(1,6001) TNA,DNA,XLNMN,XLNLT,XLNSM
        READ(1,6001) EFPP,EFGP,EFIR,EFMO,ROW,PLT
        READ(1,6001)HPD,ACRE,WIDE,XLEN
        CALL UNEQUIP(1)
        CALL OPRATE3
        CALL MANFCT3
        CALL TRNSPRT3
        CALL INSTALL3
C
C       CALCULATE AND WRITE SEASONAL ENERGY REQUIREMENTS
        TOTSEN=TENPS+ETTRP+(ESMMFT+EMMFT+ELMFT+ENINST)/20.
       1+EPPMFT/15.+ENEMFT/10.
        SENPA=TOTSEN/ACRE
        WRITE(61,6157)TOTSEN
6157    FORMAT(5X,≠TOTAL SEASONAL ENERGY=≠,F15.2,≠ KWH≠)
        WRITE(61,6158)SENPA
6158    FORMAT(5X,≠SEASONAL ENERGY PER ACRE=≠,F10.2,≠ KWH/ACRE≠)
        ENPAI=SENPA/TNA
        WRITE(61,6143)ENPAI
6143    FORMAT(5X,≠ENERGY PER ACRE-INCH=≠,F10.2,≠ KWH/ACRE-INCH≠)
        RETURN
        END


        SUBROUTINE OPRATE3
C
C       CALCULATE PUMPING ENERGY
C
        COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,NOPEM,
       1EMLN,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,HFSM,IDSM,EFMO,
       2XLNMN,IDMN,CHWM,CHWL,XLNSM,BHP,MLTY,MMTY,ROW,PLT,TLSM,
       3SPOHF,TLNMN,MNPO,ILTPO,DSMF,ACRE,DMF,DLTF,TXLNMN,TLNLT,
       4QM,XLM,IDM,NMS,HPD,DNA,TNA,EMGPH,EFIR,WIDE,NIPS,XLEN,ANLTS
       5,TENPS,ETTRP,ESMMFT,EMMFT,ELMFT,ENINST,EPPMFT,ENEMFT
        DIMENSION QM(10),XLM(10),IDM(10)
C
C       CALCULATE PUMPING RATE
        QPUMP=DNA*453.*ACRE/(HPD*EFIR)
        PLTNO=ACRE*43560./(ROW*PLT)
        XNLTS=2.*WIDE/ROW
        QPLANT=QPUMP/PLTNO
        GPHPLT=ROW*PLT*DNA*.028
        EMGPO=PLTNO/XNLTS
        TTOT=TNA*24./DNA
        WRITE(61,6187)GPHPLT,QPUMP
6187    FORMAT(5X,≠QPLANT=≠,F7.3,≠ GPH≠,5X,≠QPUMP=≠,
       1F10.2,≠ GPM≠)
```

```
      WRITE(61,6188)
6188  FORMAT(1X,≠EMITTERS-LENGTH-FLOW GPH-PRESSURE≠)
      READ(60,6021)NOPEM,EMLN,EMGPH,SPOH
6021  FORMAT(I1,F14.2,F8.2,F10.2)
      DLTF=IDLT/12.0
      SPOHF=SPOH*2.307
      TLSM=WIDE/2.
      TLNMN=XLEN/2.
      TLNLT=XLEN/2.
      QMF=QPUMP/897.66
      DSMF=IDSM/12.
      DMF=IDMN/12.0
      QLTF=QPUMP/(XNLTS*448.31)
C
C     CALCULATE TOTAL HEAD REQUIREMENTS
      HFM=(((QPUMP/448.31)*(WIDE/2.)**.54)/(((3.14*DMF**2)
     1/4.)*((DMF/4.)**.63)*(1.318*CHWM)))**1.85
      HFSM=(((QMF*(XLEN/2.)**.54)/(((3.14*DSMF**2)/4.)*
     1((DSMF/4.)**.63)*(1.318*CHWM)))**1.85)*(.351+
     2(1./XNLTS)+SQRT(.1417/(XNLTS/2.)**2))
      HFL=(((QLTF*TLNLT**.54)/(((3.14*.58**2)/4.)*((.58/4.)
     1**.63)*(1.318*CHWL)))**1.85)*(.351+(.5/EMGRO)+
     2SQRT(.1417/EMGRO**2))
      TDH=SPOHF+HFL+HFM+HFSM+STL+ELEVDF+HFSL+HFMISC
C
C     CALULATE POWER REQUIREMENT AND PUMPING ENERGY
      WHP=QPUMP*TDH/3960.
      BHP=WHP/EFPP
      IF(IPTY.GT.0) GO TO 100
      THHP=BHP/(EFGP*EFMO)
      GO TO 101
100   THHP=BHP/EFMO
101   TENPS=TTOT*THHP*.7457
      WRITE(61,6101) THHP
6101  FORMAT(10X,≠THE THERMAL HORSEPOWER=≠,F10.2)
      WRITE(61,6201) HFM,HFL,HFSM,TDH
6201  FORMAT(5X,≠HFM=≠,F10.2,/5X,≠HFL=≠,F10.2,/5X,
     1≠HFSM=≠,F10.2,/5X,≠TDH=≠,F10.2)
      WRITE(61,6190)TENPS
6190  FORMAT(5X,≠SEASONAL PUMPING ENERGY=≠,F12.2,≠ KWH≠)
      RETURN
      END

      SUBROUTINE MANFCT3
C
C     CALCULATE MANUFACTURING ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,NOPEM,
     1EMLN,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,HFSM,IDSM,EFMO,
     2XLNMN,IDMN,CHWM,CHWL,XLNSM,BHP,MLTY,MMTY,ROW,PLT,TLSM,
     3SPOHF,TLNMN,MNPO,ILTPO,DSMF,ACRE,DMF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,EMGPH,EFIR,WIDE,NIPS,XLEN,ANLTS
     5,TENPS,ETTRP,ESMMFT,EMMFT,ELMFT,ENINST,EPPMFT,ENEMFT
```

```
      DIMENSION OM(10),XLM(10),IDM(10)
      DIMENSION MD(9),AMW(9),AMCW(9),SMW(9),ABMW(9),ABMCW(9)
      DIMENSION PVMW(9),PUMPHP(20)
      DIMENSION ILD(9),ALW(9),ALCW(9),SLW(9),SLCW(9),PVLW(9)
      DATA(XNAME=≠*MAINLNS≠)
      DATA(YNAME=≠*LATERAL≠)
      DATA(PUMPHP=0.75,1.0,1.5,2.0,3.0,5.0,7.5,10.0,15.0,
     120.0,25.0,30.0,40.0,50.0,60.0,75.0,100.0,125.0,
     2150.0,200.0)
      CALL EQUIP(12,XNAME)
C
C     READ BASIC MAINLINE DATA
      READ(12,6012)(MD(J),AMW(J),AMCW(J),SMW(J),ABMW(J),
     1ABMCW(J),PVMW(J),J=1,8)
6012  FORMAT(I3,6F6.2)
      CALL UNEQUIP(12)
C
C     CALCULATE MAINLINE MANUFACTURING ENERGY
      DO 69 J=1,8
      IF(IDMN.EQ.MD(J)) GO TO 60
69    CONTINUE
60    GO TO(201,202,203,204),MMTY
201   TMNWT=TLNMN/XLNMN*(XLNMN*SMW(J))
      EMMFT=TMNWT*8.5
      GO TO 210
202   TMNWT=TLNMN/XLNMN*(XLNMN*AMW(J)+AMCW(J))
      EMMFT=TMNWT*36.
      GO TO 210
203   TMNWT=TLNMN/XLNMN*(XLNMN*PVMW(J))
      EMMFT=TMNWT*15.2
      GO TO 210
204   TMNWT=TLNMN/XLNMN*(XLNMN*ABMW(I)+ABMCW(I))
      EMMFT=TMNWT*8.0
210   CONTINUE
      WRITE(61,6112)EMMFT
6112  FORMAT(5X,≠ENERGY TO MANUFACTURE MAINLINES=≠,F10.2,
     1≠ KILOWATT-HOURS≠)
      CALL EQUIP(12,XNAME)
C
C     READ BASIC SUBMAINLINE DATA
      READ(12,6012)(MD(J),AMW(J),AMCW(J),SMW(J),ABMW(J),
     1ABMCW(J),PVMW(J),J=1,8)
      CALL UNEQUIP(12)
C
C     CALCULATE SUBMAINLINE MANUFACTURING ENERGY
      DO 64 J=1,8
      IF(IDSM.EQ.MD(J)) GO TO 67
64    CONTINUE
67    GO TO(401,402,403,404),MMTY
401   TSMNWT=2.*TLSM/XLNSM*(XLNSM*SMW(J))
      ESMMFT=TSMNWT*8.5
      GO TO 410
402   TSMNWT=2.*TLSM/XLNSM*(XLNSM*AMW(J)+AMCW(J))
      ESMMFT=TSMNWT*36.
```

```
      GO TO 410
403   TSMNWT=2.*TLSM/XLNSM*(XLNSM*PVMW(J))
      ESMMFT=TSMNWT*15.2
      GO TO 410
404   TSMNWT=2.*TLSM/XLNSM*(XLNSM*ABMW(J)+ABMCW(J))
      ESMMFT=TSMNWT*8.0
410   WRITE(61,6141)ESMMFT
6141  FORMAT(5X,≠ENERGY TO MANUFACTURE SUBMAIN=≠,F12.2,≠ KWH≠)
      CALL EQUIP(13,YNAME)
C
C     READ BASIC LATERAL DATA
      READ(13,6013)(ILD(I),ALW(I),ALCW(I),SLW(I),SLCW(I),
     1PVLW(I),I=1,5)
6013  FORMAT(I3,5F6.2)
C
C     CALCULATE LATERAL MANUFACTURING ENERGY
      DO 50 I=1,5
      IF(IDLT.EQ.ILD(I)) GO TO 59
50    CONTINUE
59    GO TO(301,302,303),MLTY
301   TLATWT=XNLTS*TLNLT/XLNLT*(XLNLT*SLW(I)+SLCW(I))
      ELMFT=TLATWT*8.5
      GO TO 310
302   TLATWT= XNLTS*TLNLT/XLNLT*(XLNLT*ALW(I)+ALCW(I))
      ELMFT=TLATWT*36.
      GO TO 310
303   TLATWT=XNLTS*TLNLT/XLNLT*(XLNLT*PVLW(I))
      ELMFT=TLATWT*15.2
310   CONTINUE
      CALL UNEQUIP(13)
      WRITE(61,6113)ELMFT
6113  FORMAT(5X,≠ENERGY TO MANUFACTURE LATERALS=≠,F10.2,
     1≠ KILOWATT-HOURS≠)
C
C     CALCULATE PUMPING UNIT MANUFACTURING ENERGY
      DO 70 I=1,20
      IF(BHP.LE.PUMPHP(I)) GO TO 40
70    CONTINUE
40    DBHP=PUMPHP(I)
      WRITE(61,6121)DBHP
6121  FORMAT(5X,≠DESIGN POWER UNIT CAPACITY=≠,F7.2,≠ HP≠)
      EPPMFT=DBHP*1163.0
      WRITE(61,6111)EPPMFT
6111  FORMAT(5X,≠ENERGY TO MANUFACTURE PUMPING PLANT=≠,
     1F10.2,≠ KILOWATT-HOURS≠)
C
C     CHOOSE EMITTER TYPE
      WRITE(61,6100)
6100  FORMAT(5X,≠ENTER NUMBER OF EMITTER TYPE.≠,/5X,
     1≠1: DRIPEZE              2: MICROTUBE≠)
      READ(60,6000)IEMTY
6000  FORMAT(I1)
```

```
C     CALCULATE EMITTER MANUFACTURING ENERGY
      IF(IEMTY.EQ.1)GO TO 10
      WTEM=NOPEM*ACRE*75.71*EMLN/(ROW*PLT)
      ENEMFT=WTEM*20.
      GO TO 11
10    WTEM=NOPEM*ACRE*6262.45/(ROW*PLT)
      ENEMFT=WTEM*20.
11    WRITE(61,6101)ENEMFT
6101  FORMAT(5X,≠ENERGY FOR EMITTERS=≠,F10.2,≠ KWH≠)
      RETURN
      END


      SUBROUTINE TRNSPRT3
C
C     NO TRANSPORTATION ENERGY FOR TRICKLE SYSTEM
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,NOPEM,
     1EMLN,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,HFSM,IDSM,EFMO,
     2XLNMN,IDMN,CHWM,CHWL,XLNSM,BHP,MLTY,MMTY,ROW,PLT,TLSM,
     3SPOHF,TLNMN,MNPO,ILTPO,DSMF,ACRE,DMF,DLTF,TXLNMN,TLNLT,
     4OM,XLM,IDM,NMS,HPD,DNA,TNA,EMGPH,EFIR,WIDE,NIPS,XLEN,ANLTS
     5,TENPS,ETTRP,ESMMFT,EMMFT,ELMFT,ENINST,EPPMFT,ENEMFT
      DIMENSION OM(10),XLM(10),IDM(10)
      ETTRP=0.0
      WRITE(61,6116)ETTRP
6116  FORMAT(5X,≠ENERGY FOR TRANSPORT=≠,F10.2,
     1≠ KILOWATT-HOURS PER SEASON≠)
      RETURN
      END


      SUBROUTINE INSTALL3
C
C     CALCULATE INSTALLATION ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,NOPEM,
     1EMLN,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,HFSM,IDSM,EFMO,
     2XLNMN,IDMN,CHWM,CHWL,XLNSM,BHP,MLTY,MMTY,ROW,PLT,TLSM,
     3SPOHF,TLNMN,MNPO,ILTPO,DSMF,ACRE,DMF,DLTF,TXLNMN,TLNLT,
     4OM,XLM,IDM,NMS,HPD,DNA,TNA,EMGPH,EFIR,WIDE,NIPS,XLEN,ANLTS
     5,TENPS,ETTRP,ESMMFT,EMMFT,ELMFT,ENINST,EPPMFT,ENEMFT
      DIMENSION OM(10),XLM(10),IDM(10)
      DATA(IYES=≠YES ≠)
      WRITE(61,6162)
6162  FORMAT(5X,≠IS MAINLINE BURIED^≠)
      READ(60,6062)MNPO
6062  FORMAT(R4)
      WRITE(61,6163)
6163  FORMAT(5X,≠ARE LATERALS BURIED^≠)
      READ(60,6063)ILTPO
6063  FORMAT(R4)
```

```
      IF(MNPO.EQ.IYES)GO TO 600
      IF(ILTPO.EQ.IYES)GO TO 601
      ENINST=0.00
      WRITE(61,6161)
6161  FORMAT(5X,≠INSTALLATION ENERGY IS NEGLIGIBLE.≠)
      GO TO 900
600   IF(ILTPO.EQ.IYES)GO TO 701
C
C     CALCULATE VOLUME OF EXCAVATION AND ENERGY REQUIREMENT
      ENINST=(TLNMN*(2.+DMF)*(.33+DMF)+2.*TLSM*
     1(2.+DSMF)*(.33+DSMF))*.3
      GO TO 800
601   ENINST=XNLTS*TLNLT*(.5+DLTF)*(.33+DLTF)*.3
      GO TO 800
701   ENINST=(XNLTS*TLNLT*(.5+DLTF)*(.33+DLTF)+TLNMN*(2.+DMF)*
     1(.33+DMF)+2.*TLSM*(2.+DSMF)*(.33+DSMF))*.3
800   WRITE(61,6164)ENINST
6164  FORMAT(5X,≠INSTALLATION ENERGY=≠,F10.2,≠ KILOWATT-HOURS≠)
900   RETURN
      END


      SUBROUTINE SIDEMOVE
C
C     SIDE ROLL SPRINKLER SYSTEM ENERGY REQUIREMENTS
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
     1OSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,IWD,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,ONA,TNA,FREQ,EFIR,WIDE,NIPS,
     5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
C
C     IWD = WHEEL DIAMETER (IN)
C     WDF = WHEEL DIAMETER (FT)
C     WWT = WHEEL WEIGHT (LB)
C     ELPMFT = ENERGY TO MANUFACTURE LATERAL PIPE (KWH)
C     EMOMFT = ENERGY TO MANUFACTURE MOVING UNIT (KWH)
C
      DIMENSION QM(10),XLM(10),IDM(10)
      DATA(PNAME=≠*XINSIDE≠)
6001  FORMAT(8F10.2)
6002  FORMAT(3I2,3I3)
      CALL EQUIP(31,PNAME)
C
C     READ BASIC INPUT DATA
      READ(31,6002) IPTY,MLTY,MMTY,IWD
      READ(31,6001) SPOH,CHWM,CHWL,STL,ELEVDF,HFSL,HFMISC
      READ(31,6001) TNA,ONA,XLNLT,XLNMN,RIHT
      READ(31,6001) EFPP,EFGP,EFIR,EFMO
      READ(31,6001) FREQ,HPD,ACRE,WIDE
      CALL UNEQUIP(31)
```

```
      CALL OPRATE4
      CALL MANFCT4
      CALL TRNSPRT4
      CALL INSTALL4
C
C     CALCULATE AND WRITE SEASONAL ENERGY VALUES
      TOTSEN=TENPS+ETTRP+(TEMMFT+ELMFT+ENINST)/20.
     1+EPPMFT/15.+ENSPMFT/10.
      WRITE(61,6100)TOTSEN
6100  FORMAT(5X,≠TOTAL SEASONAL ENERGY=≠,F20.2,≠ KWH≠)
      SENPA=TOTSEN/ACRE
      WRITE(61,6110)SENPA
6110  FORMAT(5X,≠SEASONAL ENERGY PER ACRE=≠,F15.2,≠ KWH≠)
      ENPAI=SENPA/TNA
      WRITE(61,6198)ENPAI
6198  FORMAT(5X,≠ENERGY PER ACRE INCH=≠,F10.2,≠ KWH/ACRE-IN≠)
      RETURN
      END


      SUBROUTINE OPRATE4
C
C     CALCULATE PUMPING ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,IWD,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,
     5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
C
C     CALCULATE PUMPING RATE
      TLNLT=WIDE/2.
      SPRNO=TLNLT/XLNLT
      NOSPR=IFIX(SPRNO)
      QPUMP=ACRE*DNA*453./(FREQ*HPD*EFIR)
      WRITE(61,617) QPUMP
617   FORMAT(5X,≠QPUMP=≠,F10.2,≠ GPM≠)
      WRITE(61,611)
611   FORMAT(5X,≠ENTER NUMBER OF LATERALS IN SYSTEM.(XX.)≠)
      READ(60,601) XNLTS
601   FORMAT(F10.2)
      QLT=QPUMP/XNLTS
      WRITE(61,614)QLT
614   FORMAT(5X,≠QLATERAL=≠,F7.2,≠ GPM≠)
      QSPR=QLT/NOSPR
      DNOZ=(QSPR/(28.94*SPOH**.5))**.5
      QLTF=QLT*.00223
      XNIPS=(TNA/DNA)+.99
      NIPS=IFIX(XNIPS)
      TTOT=NIPS*FREQ*HPD
      SPOHF=SPOH*2.307
```

```
C      DETERMINE MAINLINE CONFIGURATION
       WRITE(61,613)
613    FORMAT(5X,≠ENTEP NUMBER OF MAIN STEPS,LATERAL SIZE,≠,
      1/1X,≠UNDER -1,2- RESPECTIVELY≠,/1X,≠12≠)
       READ(60,603) NMS,IDLT
603    FORMAT(2I1)
       DLTF=IDLT/12.0
       WRITE(61,6198)
6198   FORMAT(1X,≠DIAMETER-FLOW RATE-LENGTH≠)
       READ(60,6021)(IDM(I),QM(I),XLM(I),I=1,NMS)
6021   FORMAT(I2,F18.2,F15.2)
C
C      CALCULATE TOTAL HEAD REQUIREMENT
       HFM=0.0
       DO 500 I=1,NMS
       DMNF=IDM(I)/12.0
       QMF=QM(I)/448.83
       HFP=((QMF*XLM(I)**.54)/(((3.14*DMNF**2)/4)*
      1((DMNF/4)**.63)*(1.318*CHWM)))**1.85
       WRITE(61,6181)I,HFP
6181   FORMAT(5X,≠HFM(INCREMENTAL)≠,I2,≠ =≠,F10.2)
       HFM=HFM+HFP
500    CONTINUE
       HFL=(((QLTF*TLNLT**.54)/(((3.14*DLTF**2)/4)*((DLTF/4)
      1**.63)*(1.318*CHWL)))**1.85)*(.351+(.5/SPRNO)+
      2SQRT(.1417/SPRNO**2))
       WDF=IWD/12.0
       TDH=SPOHF+HFL+HFM+STL+ELEVDF+HFSL+HFMISC+RIHT+WDF/2.0
C
C      CALCULATE POWER AND SEASONAL ENERGY REQUIREMENT
       WHP=QPUMP*TDH/3960.
       BHP=WHP/EFPP
       IF(IPTY.GT.0) GO TO 100
       THHP=BHP/(EFGP*EFMO)
       GO TO 101
100    THHP=BHP/EFMO
101    TENPS=TTOT*THHP/1.341
       WRITE(61,6101) THHP
6101   FORMAT(10X,≠THE THERMAL HORSEPOWER=≠,F10.2)
       WRITE(61,6201) HFM,HFL,TDH
6201   FORMAT(5X,≠HFM=≠,F10.2,/5X,≠HFL=≠,F10.2,/5X,
      1≠TDH=≠,F10.2)
       WRITE(61,6159)TENPS
6159   FORMAT(5X,≠SEASONAL PUMPING ENERGY=≠,F15.2,≠ KWH≠)
       WRITE(61,6116)DNOZ
6116   FORMAT(5X,≠NOZZLE DIAMETER=≠,F10.6,≠ IN.≠)
       RETURN
       END
```

```
      SUBROUTINE MANFCT4
C
C     CALCULATE MANUFACTURING ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,IWD,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,
     5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
      DIMENSION MD(9),AMW(9),AMCW(9),SMW(9),ABMW(9),ABMCW(9)
      DIMENSION PVMW(9),PUMPHP(20)
      DIMENSION ILD(5),ALW(5),ALCW(5),SLW(5),SLCW(5),PVLW(5)
      DATA(XNAME=≠*MAINLNS≠)
      DATA(YNAME=≠*LATERAL≠)
      DATA(PUMPHP=0.75,1.0,1.5,2.0,3.0,5.0,7.5,10.0,15.0,
     120.0,25.0,30.0,40.0,50.0,60.0,75.0,100.0,125.0,
     2150.0,200.0)
      CALL EQUIP(12,XNAME)
C
C     READ BASIC MAINLINE DATA
      READ(12,6012) (MD(J),AMW(J),AMCW(J),SMW(J),ABMW(J),
     1ABMCW(J),PVMW(J),J=1,8)
6012  FORMAT(I3,6F6.2)
      CALL UNEQUIP(12)
C
C     CALCULATE ENERGY TO MANUFACTURE MAINLINES
      TEMMFT=0.0
      DO 98 I=1,NMS
      DO 69 J=1,8
      IF(IDM(I).EQ.MD(J)) GO TO 60
69    CONTINUE
60    GO TO(201,202,203,204),MMTY
201   TMNWT=XLM(I)/XLNMN*(XLNMN*SMW(J))
      EMMFT=TMNWT*8.5
      GO TO 210
202   TMNWT=XLM(I)/XLNMN*(XLNMN*AMW(J)+AMCW(J))
      EMMFT=TMNWT*36.
      GO TO 210
203   TMNWT=XLM(I)/XLNMN*(XLNMN*PVMW(J))
      EMMFT=TMNWT*15.2
      GO TO 210
204   TMNWT=XLM(I)/XLNMN*(XLNMN*ABMW(J)+ABMCW(J))
      EMMFT=TMNWT*8.0
210   TEMMFT=TEMMFT+EMMFT
98    CONTINUE
      WRITE(61,6112)TEMMFT
6112  FORMAT(5X,≠ENERGY TO MANUFACTURE MAINLINES=≠,F10.2,
     1≠ KILOWATT-HOURS≠)
C
C     CALCULATE LATERAL MANUFACTURING ENERGY
      IF(IDLT.EQ.4) GO TO 47
      IF(IDLT.EQ.5) GO TO 57
```

```
      WRITE(61,6135)
6135  FORMAT(5X,≠LATERAL SIZE IS NOT STANDARD≠)
      GO TO 99
47    IF(IWD.EQ.48) GO TO 41
      IF(IWD.EQ.60) GO TO 42
      IF(IWD.EQ.64) GO TO 43
      IF(IWD.EQ.76) GO TO 44
45    WRITE(61,6145)
6145  FORMAT(5X,≠WHEEL SIZE IS NOT STANDARD≠)
      GO TO 99
41    WWT=38.
      GO TO 48
42    WWT=41.5
      GO TO 48
43    WWT=46.
      GO TO 48
44    WWT=60.
48    LTWT=XLNLT*(1.05)+5.4+WWT
      GO TO 61
57    IF(IWD.EQ.48) GO TO 51
      IF(IWD.EQ.60) GO TO 52
      IF(IWD.EQ.64) GO TO 53
      IF(IWD.EQ.76) GO TO 54
      GO TO 45
51    WWT=39.
      GO TO 58
52    WWT=42.5
      GO TO 58
53    WWT=47.
      GO TO 58
54    WWT=64.
58    LTWT=XLNLT*(1.42)+7.4+WWT
61    TLTWT=LTWT*XNLTS
      ELPMFT=TLTWT*36.
      EMOMFT=5000.*XNLTS
      ELMFT=ELPMFT+EMOMFT
      WRITE(61,6113)ELMFT
6113  FORMAT(5X,≠ENERGY TO MANUFACTURE LATERALS=≠,F10.2,
     1≠ KILOWATT-HOURS≠)
C
C     CALCULATE PUMPING UNIT MANUFACTURING ENERGY
C
      DO 70 I=1,20
      IF(BHP.LE.PUMPHP(I)) GO TO 40
70    CONTINUE
40    DBHP=PUMPHP(I)
      WRITE(61,6121)DBHP
6121  FORMAT(5X,≠DESIGN POWER UNIT=≠,F7.2,≠ HP CAPACITY≠)
      EPPMFT=DBHP*1163.0
      WRITE(61,6111)EPPMFT
6111  FORMAT(5X,≠ENERGY TO MANUFACTURE PUMPING PLANT=≠,
     1F10.2,≠ KILOWATT-HOURS≠)
```

```
C     CALCULATE SPRINKLER MANUFACTURING ENERGY
      WTSPR=NOSPR*XNLTS*1.1
      ENSPMFT=WTSPR*19.77
      WRITE(61,6117)ENSPMFT
6117  FORMAT(5X,≠ENERGY TO MANUFACTURE SPRINKLERS=≠,F12.2,
     1≠ KWH≠)
99    RETURN
      END




      SUBROUTINE TRNSPRT4
C
C     CALCULATE TRANSPORT ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,IWD,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,
     5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
      ETTRP=(339332.*ACRE*NIPS)/(XLNMN*XLNLT*SPRNO)
      WRITE(61,6116)ETTRP
6116  FORMAT(5X,≠ENERGY FOR TRANSPORT=≠,F10.2,
     1≠ KILOWATT-HOURS PER SEASON≠)
      RETURN
      END




      SUBROUTINE INSTALL4
C
C     CALCULATE INSTALLATION ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,IWD,
     3SPOHF,MNPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,
     5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
      DATA(IYES=≠YES ≠)
      WRITE(61,6162)
6162  FORMAT(5X,≠IS MAINLINE BURIED^≠)
      READ(60,6062)MNPO
6062  FORMAT(R4)
```

```
      IF(MNPO.EQ.IYES)GO TO 600
      ENINST=0.0
      WRITE(61,6161)
6161  FORMAT(5X,≠INSTALLATION ENERGY IS NEGLIGIBLE.≠)
      GO TO 900
C
C     CALCULATE VOLUME OF EXCAVATION AND ENERGY REQUIREMENT
600   ENINST=0.0
      DO 650 I=1,NMS
      DMNF=IDM(I)/12.0
      EMINST=XLM(I)*(2.+DMNF)*(.33+DMNF)*.3
650   ENINST=ENINST+EMINST
      WRITE(61,6164)ENINST
6164  FORMAT(5X,≠INSTALLATION ENERGY=≠,F10.2,≠ KILOWATT-HOURS≠)
900   RETURN
      END


      SUBROUTINE SOLIDSET
C
C     SOLID SET AND PERMANENT SPRINKLER SYSTEM ENERGY REQUIREMENTS
C
      COMMON/TAG/ISYSTY
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,IDSM,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,ESMMFT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,HFSM,XLSM,
     3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,XLEN,ANLTS,
     5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
C     ANLTS = NUMBER OF LATERALS OPERATING SIMULTANEOUSLY
      DATA(BNAME=≠*INSOLID≠)
      DATA(GNAME=≠*XINPERM≠)
      DIMENSION QM(10),XLM(10),IDM(10)
C
C     CHECK FLAG FOR SOLID SET OR PERMANENT SYSTEM
      IF(ISYSTY.EQ.7) GO TO 42
      CALL EQUIP(51,BNAME)
      GO TO 46
 42   CALL EQUIP(51,GNAME)
46    CONTINUE
6001  FORMAT(8F10.2)
6002  FORMAT(3I2,2I3)
C
C     READ BASIC INPUT DATA
      READ(51,6002)  IPTY,MLTY,MMTY
      READ(51,6001)  SPOH,CHWM,CHWL,STL,ELEVDF,HFSL,HFMISC
      READ(51,6001)  TNA,DNA,XLNLT,XLNMN,RIHT
      READ(51,6001)  EFPP,EFGP,EFIR,EFMO
      READ(51,6001)FREQ,HPD,TRWT,ACRE,WIDE,XLEN
      CALL UNEQUIP(51)
      CALL OPRATE5
      CALL MANFCT5
      CALL TRNSPRT5
      CALL INSTALL5
```

```
C     CALCULATE AND WRITE SEASONAL ENERGY VALUES
      TOTSEN=TENPS+ETTRP+(TEMMFT+ESMMFT+ELMFT+ENINST)/20.
     1+EPPMFT/15.+ENSPMFT/10.
      WRITE(61,6100)TOTSEN
6100  FORMAT(5X,≠TOTAL SEASONAL ENERGY=≠,F20.2,≠ KWH≠)
      SENPA=TOTSEN/ACRE
      WRITE(61,6110)SENPA
6110  FORMAT(5X,≠SEASONAL ENERGY PER ACRE=≠,F15.2,≠ KWH≠)
      ENPAI=SENPA/TNA
      WRITE(61,6166)ENPAI
6166  FORMAT(5X,≠ENERGY PER ACRE-INCH=≠,F10.2,≠ KWH/ACRE-INCH≠)
      RETURN
      END



      SUBROUTINE OPRATE5
C
C     CALCULATE PUMPING ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,IDSM,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,ESMMFT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,HFSM,XLSM,
     3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,XLEN,ANLTS,
     5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
C
C     CALCULATE PUMPING RATE
      TLNLT=WIDE/2.
      SPRNO=TLNLT/XLNLT
      XNLTS=2.*XLEN/XLNMN
      NOSPR=IFIX(SPRNO)
      QPUMP=ACRE*DNA*453./(FREQ*HPD*EFIR)
      XNIPS=(TNA/DNA)+.99
      NIPS=IFIX(XNIPS)
      TTOT=NIPS*FREQ*HPD
      WRITE(61,6187)XNLTS,QPUMP
6187  FORMAT(5X,≠≥ OF LATERALS=≠,F7.2,5X,≠QPUMP=≠,
     1F10.2,≠ GPM≠)
C
C     DETERMINE NUMBER OF LATERALS OPERATING SIMULTANEOUSLY
      WRITE(61,619)
619   FORMAT(5X,≠≥ OF LATS. OPERATING SIMULTANEOUSLY^(XX.)≠)
      READ(60,609)ANLTS
609   FORMAT(F10.2)
      QLT=QPUMP/ANLTS
      QSPR=QLT/NOSPR
      DNOZ=(QSPR/(28.94*SPOH**.5))**.5
      XLSM=XLNMN*ANLTS/2.
      WRITE(61,610)QLT
610   FORMAT(5X,≠QLATERAL=≠,F7.2,≠ GPM≠)
```

```
C     DETERMINE MAINLINE CONFIGURATION
      WRITE(61,612)
612   FORMAT(5X,≠ENTER NUMBER OF MAIN STEPS,LATERAL SIZE,≠,
     1/1X,≠UNDER -1,2- RESPECTIVELY≠,/1X,≠12≠)
      READ(60,602) NMS,IDLT
602   FORMAT(2I1)
      WRITE(61,6188)
6188  FORMAT(1X,≠DIAMETER-FLOW RATE-XLENGTH≠)
      READ(60,6021)(IDM(I),QM(I),XLM(I),I=1,NMS)
6021  FORMAT(I2,F18.2,F10.2)
      DLTF=IDLT/12.0
      QLTF=QLT*.00223
      SPOHF=SPOH*2.307
C
C     CALCULATE TOTAL HEAD REQUIREMENTS
      HFM=0.0
      DO 500 I=1,NMS
      DMNF=IDM(I)/12.0
      IDSM=IDM(I)
      DSMNF=IDSM/12.0
      QMF=QM(I)/448.83
      HFP=((QMF*XLM(I)**.54)/(((3.14*DMNF**2)/4)*
     1((DMNF/4)**.63)*(1.318*CHWM)))**1.85
      WRITE(61,6181)I,HFP
6181  FORMAT(5X,≠HFM(INCREMENTAL)≠,I2,≠ =≠,F10.2)
      HFM=HFM+HFP
500   CONTINUE
      HFL=(((QLTF*TLNLT**.54)/(((3.14*DLTF**2)/4)*((DLTF/4)
     1**.63)*(1.318*CHWL)))**1.85)*(.351+(.5/SPRNO)+
     2SQRT(.1417/SPRNO**2))
      HFSM=(((QLTF*ANLTS*(XLNMN*ANLTS/2.)**.54)/(((3.14*
     1DSMNF**2)/4.)*((DSMNF/4.)**.63)*(1.318*CHWM)))**1.85)*
     2(.333+(1./ANLTS)+SQRT(.1417/(ANLTS/2.)**2))
      TDH=SPOHF+HFL+HFM+HFSM+STL+ELEVDF+HFSL+HFMISC+RIHT
C
C     CALCULATE POWER AND PUMPING ENERGY REQUIREMENTS
      WHP=QPUMP*TDH/3960.
      BHP=WHP/EFPP
      IF(IPTY.GT.0) GO TO 100
      THHP=BHP/(EFGP*EFMO)
      GO TO 101
100   THHP=BHP/EFMO
101   TENPS=TTOT*THHP*.7457
      WRITE(61,6101) THHP
6101  FORMAT(10X,≠THE THERMAL HORSEPOWER=≠,F10.2)
      WRITE(61,6201) HFM,HFL,HFSM,TDH
6201  FORMAT(5X,≠HFM=≠,F10.2,/5X,≠HFL=≠,F10.2,/5X,
     1≠HFSM=≠,F10.2,/5X,≠TDH=≠,F10.2)
      WRITE(61,6189)DNOZ
6189  FORMAT(5X,≠SPRINKLER NOZZLE DIAMETER=≠,F8.6,≠ IN.≠)
      WRITE(61,6190)TENPS
6190  FORMAT(5X,≠SEASONAL PUMPING ENERGY=≠,F12.2,≠ KWH≠)
      RETURN
      END
```

```
      SUBROUTINE MANFCT5
C
C     CALCULATE MANUFACTURING ENERGY
C
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,IDSM,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,ESMMFT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,HFSM,XLSM,
     3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,XLEN,ANLTS,
     5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
      DIMENSION MD(9),AMW(9),AMCW(9),SMW(9),ABMW(9),ABMCW(9)
      DIMENSION PVMW(9),PUMPHP(20)
      DIMENSION ILD(9),ALW(9),ALCW(9),SLW(9),SLCW(9),PVLW(9)
      DATA(XNAME=≠*MAINLNS≠)
      DATA(YNAME=≠*LATERAL≠)
      DATA(PUMPHP=0.75,1.0,1.5,2.0,3.0,5.0,7.5,10.0,15.0,
     120.0,25.0,30.0,40.0,50.0,60.0,75.0,100.0,125.0,
     2150.0,200.0)
      CALL EQUIP(12,XNAME)
C
C     READ BASIC MAINLINE DATA
      READ(12,6012)(MD(J),AMW(J),AMCW(J),SMW(J),ABMW(J),
     1ABMCW(J),PVMW(J),J=1,8)
6012  FORMAT(I3,6F6.2)
      CALL UNEQUIP(12)
      TEMMFT=0.0
C
C     CALCULATE MAINLINE MANUFACTURING ENERGY
      DO 99 I=1,NMS
      DO 69 J=1,8
      IF(IDM(I).EQ.MD(J)) GO TO 60
69    CONTINUE
60    GO TO(201,202,203,204),MMTY
201   TMNWT=XLM(I)/XLNMN*(XLNMN*SMW(J))
      EMMFT=TMNWT*8.5
      GO TO 210
202   TMNWT=XLM(I)/XLNMN*(XLNMN*AMW(J)+AMCW(J))
      EMMFT=TMNWT*36.
      GO TO 210
203   TMNWT=XLM(I)/XLNMN*(XLNMN*PVMW(J))
      EMMFT=TMNWT*15.2
      GO TO 210
204   TMNWT=XLM(I)/XLNMN*(XLNMN*ABMW(J)+ABMCW(J))
      EMMFT=TMNWT*8.0
210   TEMMFT=TEMMFT+EMMFT
99    CONTINUE
      WRITE(61,6112)TEMMFT
6112  FORMAT(5X,≠ENERGY TO MANUFACTURE MAINLINES=≠,F10.2,
     1≠ KILOWATT-HOURS≠)
```

```
C     CALCULATE SUBMAINLINE MANUFACTURING ENERGY
      DO 64 J=1,8
      IF(IDSM.EQ.MD(J)) GO TO 67
64    CONTINUE
67    GO TO(401,402,403,404),MMTY
401   TSMNWT=XLSM/XLNMN*(XLNMN*SMW(J))
      ESMMFT=TSMNWT*8.5
      GO TO 410
402   TSMNWT=XLSM/XLNMN*(XLNMN*AMW(J)+AMCW(J))
      ESMMFT=TSMNWT*36.
      GO TO 410
403   TSMNWT=XLSM/XLNMN*(XLNMN*PVMW(J))
      ESMMFT=TSMNWT*15.2
      GO TO 410
404   TSMNWT=XLSM/XLNMN*(XLNMN*ABMW(J)+ABMCW(J))
      ESMMFT=TSMNWT*8.0
410   WRITE(61,6141)ESMMFT
6141  FORMAT(5X,≠ENERGY TO MANUFACTURE SUBMAIN=≠,F12.2,≠ KWH≠)
      CALL EQUIP(13,YNAME)
C
C     READ BASIC LATERAL DATA
      READ(13,6013)(ILD(I),ALW(I),ALCW(I),SLW(I),SLCW(I),
     1PVLW(I),I=1,5)
6013  FORMAT(I3,5F6.2)
C
C     CALCULATE LATERAL MANUFACTURING ENERGY
      DO 50 I=1,5
      IF(IDLT.EQ.ILD(I)) GO TO 59
50    CONTINUE
59    GO TO(301,302,303),MLTY
301   RIWT=(RIHT*0.4)+0.2
      TLATWT=XNLTS*SPRNO*(XLNLT*SLW(I)+SLCW(I)+RIWT)
      ELMFT=TLATWT*8.5
      GO TO 310
302   RIWT=RIHT*0.6
      TLATWT= XNLTS*SPRNO*(XLNLT*ALW(I)+ALCW(I)+RIWT)
      ELMFT=TLATWT*36.
      GO TO 310
303   RIWT=RIHT*0.15
      TLATWT=XNLTS*SPRNO*(XLNLT*PVLW(I)+RIWT)
      ELMFT=TLATWT*15.2
310   CONTINUE
      CALL UNEQUIP(13)
      WRITE(61,6113)ELMFT
6113  FORMAT(5X,≠ENERGY TO MANUFACTURE LATERALS=≠,F15.2,
     1≠ KILOWATT-HOURS≠)
C
C     CALCULATE SPRINKLER MANUFACTURING ENERGY
      TSPRWT=SPRNO*XNLTS*1.1
      ENSPMFT=TSPRWT*19.77
      WRITE(61,6149)ENSPMFT
6149  FORMAT(5X,≠ENERGY TO MANUFACTURE SPRINKLERS=≠,F15.2,
     1≠ KWH≠)
```

```
C       CALCULATE PUMPING UNIT MANUFACTURING ENERGY
        DO 70 I=1,20
        IF(BHP.LE.PUMPHP(I)) GO TO 40
70      CONTINUE
40      DBHP=PUMPHP(I)
        WRITE(61,6121)DBHP
6121    FORMAT(5X,≠DESIGN POWER UNIT CAPACITY=≠,F7.2,≠ HP≠)
        EPPMFT=DBHP*1163.0
        WRITE(61,6111)EPPMFT
6111    FORMAT(5X,≠ENERGY TO MANUFACTURE PUMPING PLANT=≠,
       1F10.2,≠ KILOWATT-HOURS≠)
        RETURN
        END
```

```
        SUBROUTINE TRNSPRT5
C
C       CALCULATE TRANSPORT ENERGY
C
        COMMON/TAG/ISYSTY
        COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,IDSM,
       1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,ESMMFT,EFMO,
       2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,HFSM,XLSM,
       3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
       4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,XLEN,ANLTS,
       5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
        DIMENSION QM(10),XLM(10),IDM(10)
C
C       CHECK FLAG:  IF A PERMANENT SYSTEM, TRANSPORT ENERGY
C       IS NEGLIGIBLE
        IF(ISYSTY.EQ.7) GO TO 43
        ETRMFT=TRWT*8.5/20.
        EFTRP=WIDE*XNLTS/235.
        ETTRP=ETRMFT+EFTRP
        GO TO 49
43      ETTRP=0.00
49      WRITE(61,6116)ETTRP
6116    FORMAT(5X,≠ENERGY FOR TRANSPORT=≠,F10.2,
       1≠ KILOWATT-HOURS PER SEASON≠)
        RETURN
        END
```

```
      SUBROUTINE INSTALL5
C
C     CALCULATE INSTALLATION ENERGY
C
      COMMON/TAG/ISYSTY
      COMMON SPOH,HFL,HFM,STL,ELEVDF,HFSL,HFMISC,SPRNO,IDSM,
     1QSPR,EFPP,EFGP,IPTY,THHP,XNLTS,XLNLT,IDLT,ESMMFT,EFMO,
     2XLNMN,IDMN,RIHT,CHWM,CHWL,XNLT,BHP,MLTY,MMTY,HFSM,XLSM,
     3SPOHF,TRWT,MNPO,ILTPO,XNIPS,ACRE,DMNF,DLTF,TXLNMN,TLNLT,
     4QM,XLM,IDM,NMS,HPD,DNA,TNA,FREQ,EFIR,WIDE,NIPS,XLFN,ANLTS,
     5TENPS,TEMMFT,ELMFT,EPPMFT,ETTRP,ENINST,ENSPMFT,NOSPR
      DIMENSION QM(10),XLM(10),IDM(10)
      DATA(IYES=≠YES ≠)
C
C     CHECK FLAG:  IF A SOLID SET SYSTEM, INSTALLATION ENERGY
C     IS NEGLIGIBLE
      IF(ISYSTY.EQ.5) GO TO 72
C
C     CALCULATE VOLUME OF EXCAVATION AND ENERGY REQUIREMENT
      EMINST=0.0
      DO 650 I=1,NMS
      DMNF=IDM(I)/12.0
      PMINST=XLM(I)*(2.+DMNF)*(.33+DMNF)*.3
650   PMINST=PMINST+EMINST
      ELINST=XNLTS*TLNLT*(2.+DLTF)*(.33+DLTF)*.3
      ESMINST=XLSM*(2.+IDSM/12.)*(.33+IDSM/12.)*.3
      WRITE(61,6162)
6162  FORMAT(5X,≠IS MAINLINE BURIED^≠)
      READ(60,6062)MNPO
6062  FORMAT(R4)
      WRITE(61,6163)
6163  FORMAT(5X,≠ARE LATERALS BURIED^≠)
      READ(60,6063)ILTPO
6063  FORMAT(R4)
      IF(MNPO.EQ.IYES)GO TO 600
      IF(ILTPO.EQ.IYES)GO TO 601
72    ENINST=0.0
      WRITE(61,6161)
6161  FORMAT(5X,≠INSTALLATION ENERGY IS NEGLIGIBLE.≠)
      GO TO 900
600   IF(ILTPO.EQ.IYES)GO TO 701
      ENINST=EMINST+ESMINST
      GO TO 800
701   ENINST=EMINST+ESMINST+ELINST
      GO TO 800
601   ENINST=ELINST
      GO TO 800
800   WRITE(61,6164)ENINST
6164  FORMAT(5X,≠INSTALLATION ENERGY=≠,F10.2,≠ KILOWATT-HOURS≠)
900   RETURN
      END
```

```
      SUBROUTINE FURROW
C
C     SURFACE IRRIGATION SYSTEM ENERGY REQUIREMENTS
C
      DATA(PUMPHP=.75,1.,1.5,2.,3.,5.,7.5,10.,15.,20.,25.,30.,
     140.,50.,60.,75.,100.,125.,150.,200.)
      DATA(XNAME=≠*MAINLNS≠)
      DATA(IYES=≠YES ≠)
      DIMENSION MD(9),AMW(9),AMCW(9),PUMPHP(20)
      DATA(QNAME=≠*XINSURF≠)
C
C     HAUL = AVERAGE LENGTH OF HAUL FOR LEVELER (FT)
C     YARD = LEVELER HAUL CAPACITY (CU.YD.)
C     DE TH = NET APPLICATION (IN/IRRIGATION)
C     XDAYS = IRRIGATION FREQUENCY (DAYS)
C     TOTAL = SEASONAL APPLICATION (IN/SEASON)
C     ITRTY = LEVELING TRACTOR TYPE
C     ENPYD = LEVELING ENERGY PER YARD (KWH/CU.YD.)
C     ENPAC = LEVELING ENERGY PER ACRE (KWH/AC)
C     TOLEN = TOTAL LEVELING ENERGY (KWH)
C     IRTY = TYPE OF SURFACE IRRIGATION
C     ENDN = ENERGY TO MAKE DISTRIBUTION NETWORK (KWH/AC)
C     TENDN = TOTAL ENERGY TO MAKE DISTRIBUTION NETWORK (KWH)
C     IPUMP = FLAG INDICATING PUMPING REQUIREMENT
C     STL = STATIC PUMPING LIFT (FT)
C     IHDTY = FLAG INDICATING HEAD DITCH TYPE
C     ENHD = ENERGY TO MAKE HEAD DITCH (KWH)
C     ENHDPA = ENERGY TO MAKE HEAD DITCH PER ACRE (KWH/AC)
C     IMD = DIAMETER OF GATED PIPE (IN)
C     ENGP = ENERGY TO MAKE GATED PIPE (KWH)
C     ICDTY = FLAG INDICATING TYPE OF CONTROL DEVICE
C     ENST = ENERGY TO MAKE SIPHON TUBES (KWH)
C     XNOTO = NUMBER OF TURNOUTS REQUIRED
C     ENTO = ENERGY TO MAKE TURNOUTS
C     ENCPA = ENERGY TO MAKE CONTROL DEVICES PER ACRE (KWH/ACRE)
C
      CALL EQUIP(6,QNAME)
C
C     READ BASIC INPUT DATA
      READ(6,6000)HAUL,YARD,WIDE,XLEN,DEPTH,XDAYS,TOTAL
      CALL UNEQUIP(6)
C
C     CALCULATE ENERGY FOR FIELD LEVELING
      ACRE=WIDE*XLEN/43560.
 6000 FORMAT(7F8.2)
      WRITE(61,6101)
 6101 FORMAT(5X,≠ENTER NUMBER OF TRACTOR USED IN FIELD LEVELING≠
     1,/5X,≠1: D7 AND 10 CU.YD. CARRYALL≠,/5X,
     2≠2: D8 AND 14 CU.YD. CARRYALL≠,/5X,
     3≠3: D9 AND 20 CU.YD. CARRYALL≠)
      READ(60,6001)ITRTY
 6001 FORMAT(I1)
      GO TO(11,12,13)ITRTY
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11    ENPYD=289./(151.36-.0736*HAUL)
      GO TO 20
12    ENPYD=450./(200.-.1025*HAUL)
      GO TO 20
13    ENPYD=605./(284.5-.1393*HAUL)
20    ENPAC=ENPYD*YARD/25.
      TOLEN=ENPAC*ACRE
      WRITE(61,6102)ENPAC
6102  FORMAT(5X,≠LEVELING ENERGY=≠,F10.2,≠ KWH/ACRE≠)
C
C     CALCULATE ENERGY FOR MAKING FURROWS OR CORRUGATIONS
      WRITE(61,6103)
6103  FORMAT(5X,≠ENTER NUMBER OF IRRIGATION TYPE≠,/5X,
     1≠1: FURROWS          2: CORRUGATIONS≠)
      READ(60,6001)IRTY
      IF(IRTY.EQ.1)GO TO 30
      ENDN=50.21
      TENDN=ENDN*ACRE
      SPACE=1.67
      WRITE(61,6123)ENDN
6123  FORMAT(5X,≠ENERGY TO MAKE CORRUGATES=≠,F10.2,≠ KWH/ACRE≠)
      GO TO 41
30    ENDN=48.50
      TENDN=ENDN*ACRE
      SPACE=3.
      WRITE(61,6104)ENDN
6104  FORMAT(5X,≠ENERGY TO MAKE FURROWS=≠,F10.2,≠ KWH/ACRE≠)
C
C     CHECK IF PUMPING IS REQUIRED AND CALCULATE PUMPING
C     ENERGY IF NECESSARY
41    WRITE(61,6110)
6110  FORMAT(5X,≠IS PUMPING REQUIRED TO IRRIGATE^(YES-NO)≠)
      READ(60,6010)IPUMP
6010  FORMAT(R4)
      IF(IPUMP.EQ.IYES)GO TO 70
      ENPUMP=0.0
      WRITE(61,6111)
6111  FORMAT(5X,≠NO PUMPING ENERGY REQUIRED≠)
      GO TO 63
70    WRITE(61,6112)
6112  FORMAT(5X,≠ENTER STATIC LIFT,SOURCE-TO-FIELD,(FT)≠)
      READ(60,6012)STL
6012  FORMAT(F10.2)
C
C     CALCULATE ENERGY TO MAKE HEAD DITCH
63    WRITE(61,6107)
6107  FORMAT(5X,≠ENTER NUMBER OF HEAD DITCH TYPE≠,/5X,
     1≠1: UNLINED   2: CONCRETE LINED   3: GATED PIPE≠)
      READ(60,6005)IHDTY
      GO TO(31,32,33)IHDTY
31    ENHD=.01*WIDE
      ENHDPA=ENHD/ACRE
      GO TO 60
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32     ENHD=111.65*WIDE
       ENHDPA=ENHD/(ACRE*25.)
       GO TO 60
33     CALL EQUIP(16,XNAME)
       READ(16,6016)(MD(J),AMW(J),AMCW(J),J=1,8)
6016   FORMAT(I3,2F6.2)
       CALL UNEQUIP(16)
       WRITE(61,6108)
6108   FORMAT(5X,≠ENTER DIAMETER OF GATED PIPE IN INCHES≠
      1≠ (RIGHT JUSTIFY) XX≠)
       READ(60,6008)IMD
6008   FORMAT(I2)
       DO 57 J=1,8
       IF(IMD.EQ.MD(J))GO TO 58
57     CONTINUE
58     ENGP=(WIDE/30.)*(30.*AMW(J)+AMCW(J))
       ENHDPA=ENGP/(ACRE*20.)
       WRITE(61,6119)ENHDPA
6119   FORMAT(5X,≠ENERGY FOR GATED PIPE=≠,F10.2,≠ KWH/ACRE≠)
       GO TO 69
60     WRITE(61,6109)ENHDPA
6109   FORMAT(5X,≠ENERGY FOR DISTRIBUTION STRUCTURE=≠,
      1F10.2,≠ KWH/ACRE≠)
C
C      CALCULATE ENERGY FOR MAKING SIPHON TUBES,
C      TURNOUTS, OR SPILLS.
       WRITE(61,6105)
6105   FORMAT(5X,≠ENTER NUMBER OF CONTROL TYPE USED≠,/5X,
      1≠1: SIPHON TUBES≠,/5X,≠2: EARTH TURNOUTS≠,/5X,
      2≠3: CONCRETE TURNOUTS≠)
       READ(60,6005)ICOTY
6005   FORMAT(I1)
       GO TO(21,22,23)ICOTY
21     XNOST=WIDE/SPACE
       ENST=XNOST*10.34
       ENCPA=ENST/(ACRE*20.)
       GO TO 50
22     ENCPA=0.0
       GO TO 50
23     XNOTO=WIDE/(SPACE*3.)
       ENTO=XNOTO*126.26
       ENCPA=ENTO/(ACRE*25.)
50     WRITE(61,6106)ENCPA
6106   FORMAT(5X,≠ENERGY FOR CONTROL DEVICES=≠,F10.2,≠ KWH/ACRE≠)
       GO TO 73
69     WRITE(61,6113)
6113   FORMAT(5X,≠ENTER NUMBER OF ROWS IRRIGATED SIMULTANEOUSLY≠,
      1≠ XXX.≠)
       READ(60,6012)XNROW
       IF(IRTY.EQ.1)GO TO 71
       XL=XNROW*1.67
       XM=WIDE-XL
       GO TO 72
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71    XL=XNROW*3.
      XM=WIDE-XL
72    AREA=XL*XLEN/43560.
      Q=453.*AREA*DEPTH/(24.*XDAYS*.5)
      D=IMD/12.0
      HF=(((Q/448.83)*(XM**.54))/(((3.14*D*D)/4.)*((D/4.)**.63)
     1*158.16))**1.85
      HFL=(((Q/448.83)*(XL**.54))/(((3.14*D*D)/4.)*((D/4.)**.63)
     1*158.16))**1.85
     2*(.351+(.5/XNROW)+SQRT(.1417/(XNROW*XNROW)))
      TDH=HF+HFL+STL
      GO TO 80
73    IF(IPUMP.NE.IYES)GO TO 90
      Q=453.*ACRE*DEPTH/(24.*XDAYS*.5)
      TDH=STL
80    BHP=(Q*TDH)/2693.
      FHP=(Q*TDH)/710.9
      ENFUEL=((TOTAL*ACRE*FHP)/(453.*Q))*.746
      DO 78 I=1,20
      IF(BHP.LE.PUMPHP(I))GO TO 79
78    CONTINUE
79    DBHP=PUMPHP(I)
      ENPP=DBHP*58.15
      ENPUMP=(ENFUEL+ENPP)/ACRE
      WRITE(61,6114)Q,DBHP,ENPUMP
6114  FORMAT(5X,≠PUMPING RATE=≠,F10.2,≠ GAL/MIN.≠,/5X,
     1≠MOTOR CAPACITY=≠,F10.2,≠ BHP.≠,/5X,
     2≠SEASONAL PUMPING ENERGY=≠,F10.2,≠ KWH/ACRE≠)
C
C     WRITE OUT SEASONAL ENERGY VALUES
90    TOTEN=ENPAC+ENDN+ENCPA+ENHDPA+ENPUMP
      TENPAI=TOTEN/TOTAL
      WRITE(61,6115)TOTEN,TENPAI
6115  FORMAT(5X,≠TOTAL ENERGY PER ACRE=≠,F12.2,≠ KWH/ACRE≠
     1,/5X,≠TOTAL ENERGY PER ACRE-INCH=≠,F12.2,
     2≠KWH/ACRE-INCH≠)
      RETURN
      END
```