ENERGY INPUTS TO IRRIGATION

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211(d)- 8

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ENERGY INPUTS TO IRRIGATION*

by

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Abstract

Energy inputs to irrigation are dramatically increasing as irrigated agriculture expands to meet world food demands and more sophisticated technologies are developed to increase water use efficiency. In this study nine irrigation systems, designed for a specific land area, are analyzed and the total energy inputs computed for each system. The analysis includes energy inputs to manufactured components and installation as well as operation and maintenance. The expected life of each system and the energy value of salvagable materials are also taken into account. It is concluded that a practical balance must be established between maximizing water use efficiency and minimizing energy inputs to the irrigation system.

Key words: Energy, inputs, irrigation, system installation, and system operation.

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Introduction

Estimates that only about 3.5% of the nation's energy is devoted to agriculture[7]† at the farm level, and only about 5% of the nation's farmland is irrigated may cause one to conclude that energy inputs to irrigation are negligible. We suggest that there are additional factors to consider and that energy inputs to irrigation are by no means inconsequential.

Modern irrigation has evolved into a very energy intensive technology. On many irrigated farms, delivering water to the field requires more energy than all other farm operations combined[13,14,15]. If modern irrigation methods were employed to fully develop the irrigation potential in the U.S. the energy inputs to agricultural production would need to be increased by over 30%. This would increase agriculture's share of the nation's energy to over 5%.

Irrigated agriculture is rapidly expanding to meet world food demands. Figure 1 indicates that the total number of acres irrigated in the United States has increased from about 20 million acres in 1930 to some 50 million acres in 1972 and the number of acres under sprinkle systems increased from 4 million in 1960 to more than 10 million in 1972[8] (the total farmland cropped was approximately 350 million acres in 1972). Certain areas have ample water supplies and undeveloped land which together with high demand for agricultural products provide the incentive for bringing more acres under irrigation. Furthermore, there is also incentive to "upgrade" existing irrigation systems to increase yields per unit water.

Production of the new high yield hybrid varieties of crops in many locations require irrigation where the traditional crops did not. Almost every scenerio which has been developed regarding increased production of food on a world-wide basis involves vastly expanded irrigation. About 2300 new pumped irrigation systems requiring an annual operating energy equivalent to 15 million gallons of diesel fuel are estimated to have been installed in Nebraska alone during 1973[4].

The quantities of electrical energy involved in pumping irrigation water are rather impressive. For example, the Idaho Power Company in 1973, provided more than 1.13 billion kilowatt-hours of electricity to pump water for 1.27 million acres in its service area[11] which reduces to nearly 900 KWH/acre. At this rate, six acres of land under pumped irrigation would have about the annual electrical energy requirements as a typical American home. It is interesting to note that some 68% of all electricity used in California's agriculture goes into irrigation[3].

The high energy inputs to pumped irrigation have other important implications. The peak seasonal demand placed on many electrical power generating systems for extensive irrigation pumping necessitates significantly greater power generating capacity than would otherwise be required. Economics,

†Numbers refer to the listed references.

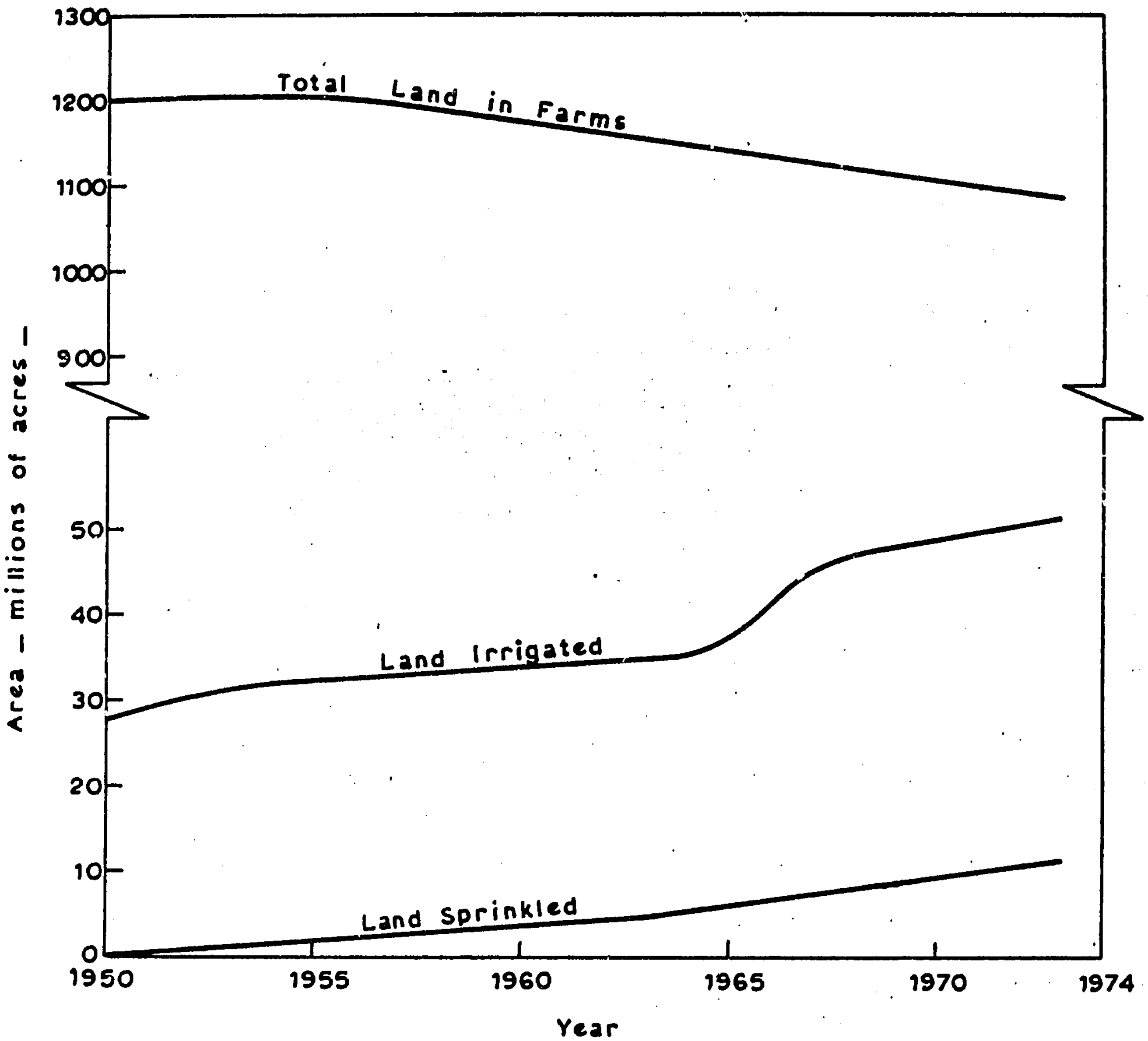

Figure 1. Total land in U. S. farms [17] compared with land irrigated and sprinkled[8].

then, dictates that this excess generating capacity be used in the off pumping season for such uses as electric heating of homes which results in campaigns to promote greater energy use in an era of energy shortage.

The trend toward even more sophisticated irrigation systems to improve irrigation efficiency and reduce labor costs has developed during an era of low energy costs and in areas where energy supplies were plentiful. Consequently, little attention has been paid to the total energy inputs involved. With decreasing energy supplies and increasing costs, an awareness of total energy flows becomes essential if the industry of irrigated agriculture is to compete with non-irrigated agriculture in the production of food. This is especially important when viewing the total world food production. If the entire world's irrigation potential were fully developed with the present sophisticated methods we estimate that between 5 and 10% of the world's annual energy expenditure would need to be devoted to irrigation alone.

It seems obvious that different types of irrigation systems may require vastly different energy inputs. The simple diversion of a small natural stream onto suitable terrain may involve only minimal amounts of human muscle energy while a system which pumps water from a deep well through an elaborate distribution set-up composed of tons of plastic, steel, or concrete involves tremendous energy inputs.

We see a need for detailed comparison of the energy inputs to various types of irrigation systems which may be applied to a specific land area. We have attempted to account for the direct energy inputs in installing and operating several different irrigation systems designed for an actual 160-acre (64-hectare) farm.

Irrigation Systems Studied

A topographic map of the farm is shown in Figure 2 with the water source from a well as indicated. The following nine different irrigation systems were designed for this land area:

1. Surface irrigation system using an open-ditch distribution network, (Surface w/o IRRS).

2. Surface irrigation system using a gated-pipe distribution network and an Irrigation Runoff Recovery System, IRRS, (Surface w/ IRRS).

3. Solid-set, aluminum lateral-pipe sprinkle irrigation system.

4. Permanent, buried plastic lateral-pipe sprinkle irrigation system.

5. Hand-moved, portable aluminum lateral-pipe sprinkle irrigation system.

6. Side-roll, aluminum lateral-pipe with steel wheels, sprinkle irrigation system.

7. Center-pivot sprinkle irrigation system.

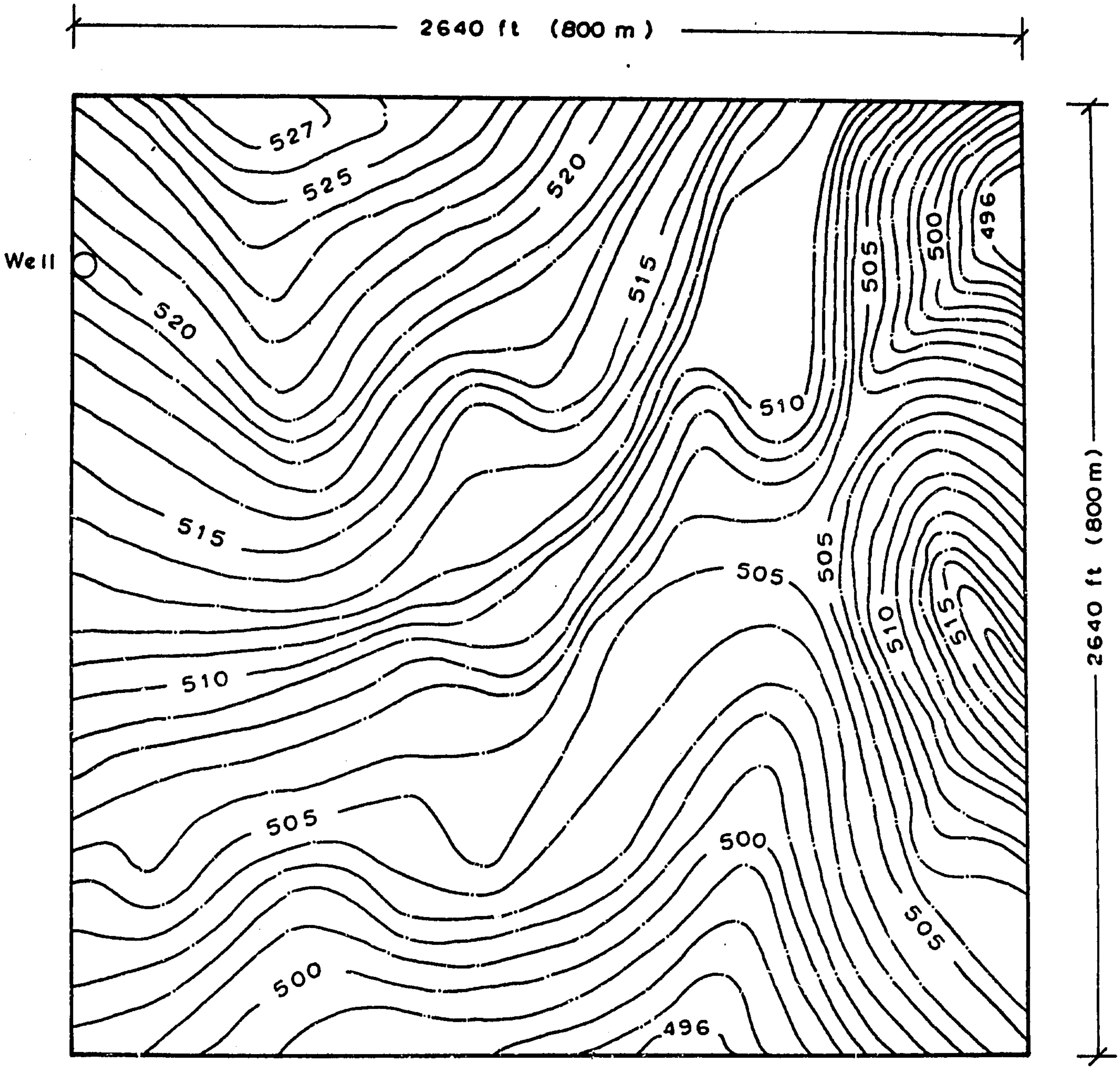

Figure 2. Topographic map, with 1-foot contour interval, of the field irrigated.

8. Big-gun traveler sprinkle irrigation system.

9. Trickle irrigation system.

The nine designs are depicted in Figures 6 through 13 in Appendix II, along with the system capacities and inlet heads required to meet a peak use rate of 0.33 in/day (8.4 mm/day). The quantities of the various materials used are listed in Table 1. The systems are not all interchangeable in terms of crops. For example, the trickle system is designed for a permanent orchard crop while the center-pivot system is only for low crops.

Energy Inputs in System Installation

The installation of an irrigation system requires excavation, piping, fittings, delivery system, structures, pumping units, and human labor. A detailed accounting of all energy flows associated with each of these items becomes very involved and we have attempted to account only for the major direct energy inputs. For example, the energy required in the manufacture of piping was considered but not the energy required to deliver the pipe to the construction site from the place of manufacture. The energy associated with labor was estimated but no attempt was made to compute the indirect energy costs associated with the vehicle and highway systems which may have transported the worker to or from the job site. No accounting was made of the energy inputs associated with the various systems which may be involved in delivering the water to the farm even though it is recognized that such energy inputs may be significant, particularly if some large development project is involved.

In this analysis we have computed the quantity of plastic, aluminum, steel, or brass involved in piping and fittings (Table 1). We estimated the energy required to manufacture these products by correlating available data from the literature (Appendix I). A similar procedure was followed in arriving at the energy required to produce pumping units, electrical motors, and diesel engines. Excavation energies were arrived at by determining the weight, horsepower, and probable life of the excavating machine used and prorating the energy of manufacture over the time required for the job at hand. The energy required to operate the excavating equipment was calculated from the fuel consumption data (Appendix I).

We recognize that technological advancement may dramatically change manufacturing energy inputs. The Toth process for producing aluminum is claimed to require only one-tenth the energy required by the traditional bayer-Hall process[16]. It is also assumed that about 40-50% of the energy originally used to produce aluminum pipes and brass fittings from raw ore should be charged to future uses of the recycled material since the energy required to produce molten aluminum from collected scrap is only about 4% of the energy required to produce molten aluminum from raw ore. A large fraction of the energy required to manufacture polyethylene and PVC pipe is also locked into the structure of the product and theoretically should be recoverable, however, no technology has yet been developed to recycle these materials.

Table 1. Design summary of the nine irrigation systems.

Irrigation System	Irrigation Efficiency % †	Area Irrigated acres	System Inlet Flow gpm	System Inlet Head ft	System Inlet Power HP	Pipe Polyeth. tons	Pipe PVC tons	Pipe Alumin. tons	Other Equipment tons	Earth Work Leveling cu yd	Earth Work Ditching ft
Surface w/o IRRS	50	156	1300	5	2		0.26			128,000*	7890
Surface w/ IRRS	85	155	1300 500	5 30	2 5		2.66	5.00		131,500	7890
Solid-set Sprinkle	80	158	1275	175	75		7.11	38.10	9.53		3750
Permanent Sprinkle	80	158	1275	175	75		30.46		10.56		147180
Hand-moved Sprinkle	75	158	1300	173	76		7.11	2.78	9.61		3750
Side-roll Sprinkle	75	158	1300	173	76		7.11	4.76	2.80		3750
Center-pivot Sprinkle	80	125	974	196	65		4.18		17.50		1500
Traveler Sprinkle	70	152	1300	312	136		9.71	0.03	8.32		5107
Trickle	90	158	1153	115	45	14.38	18.62		0.85		7826

† Assumed numbers for determining system capacities for the specific systems as designed for a net capacity of 0.33 in/day (8.4 mm/day), see Figures 6 through 13 in Appendix II.

* These numbers are relatively high because of field topography (see Figure 2).

An accounting of human-labor energy inputs was made by assuming that a man expends approximately 3000 Kcal during a 10-hour working day from which 300 Kcal are assigned to each man-hour. It is interesting to note how much more precious a Kcal of energy in human-labor energy is than a Kcal of energy in a gallon of diesel fuel. The human-labor energies are a very minor fraction of the total energy and yet the dollar cost of that human energy is a sizeable fraction of the total dollar costs.

A comparison of energy inputs to different irrigation systems must take into account the probable life of each system. It is obvious that a significantly greater energy investment could be justified in the installation of a system having comparable operational energy requirements and a useful life double that of an alternative installation. We have assigned the probable life values shown in Table 2 to the materials under consideration.

An overall comparison time-period of 20 years is used and energy inputs to those materials having probable-life times less than 20 years are multiplied by the appropriate factor. For instance, the energy associated with steel fittings, which have an expected life of 10 years, is multiplied by 2 to produce the energy needed for 20-year period.

Using the designs presented and following the procedure outlined above and in Appendix I, the energy required for installation was calculated for each system. The results are shown in Table 3.

Energy Inputs in System Operation

The energy associated with irrigation system operation includes maintenance energy and pumping energy. The annual maintenance energy was roughly estimated as 3% of the installation energy for all systems except the solid-set sprinkle system where 1% is used even though it is recognized that there may be some inequities in such assumptions.

Table 2. Probable life of various component materials used for irrigation systems.

Basic Material	Assumed Life - years
Aluminum (irrigation tubing)	20
Brass (sprinklers)	7
Steel (irrigation machinery and some fittings)	10
PVC Plastic - buried (supply pipe lines)	20
Polyethylene Plastic (trickle irrigation hoses)	10
Pumping Plant - diesel	10
Pumping Plant - electric	10

Table 3. Energy inputs in millions of Kcal associated with the installation of the nine irrigation systems on the 160-acre (64-hectare) sample field. †

Irrigation System	Pumping Unit	Pipe			Other* Equipment	Earth Work Machinary			Labor	Total **
		Polyethylene	PVC	Aluminum*		Leveling	Ditching	Fuel		
Surface w/o IRRS	2.0		0.7			256.0	1.8	229.7	0.1	492.3
Surface w/ IRRS	7.0		72.7	150.0		162.4	1.8	230.5	0.1	730.0
Solid-set Sprinkle	75.0		190.0	1140.0	442.6		0.8	1.7	0.1	1923.4
Permanent Sprinkle	75.0		807.0		385.4		15.6	55.2	1.1	1514.6
Hand-moved Sprinkle	76.0		190.0	83.5	20.7		0.8	1.7	0.1	490.0
Side-roll Sprinkle	76.0		190.0	124.7	34.5		0.8	1.7	0.1	614.6
Center-pivot Sprinkle	65.0		109.0		350.0		0.3	0.7	0.1	942.0
Traveler Sprinkle	136.0		377.0	0.9	66.4		1.2	2.3	0.1	852.7
Trickle	45.0	503.0	484.0		15.0		4.0	11.0	0.4	1630.0

† The decimal points do not indicate the estimated accuracy of the numbers but simply result from the calculational procedures described in the text.

* Calculations were based upon 50% salvage value from aluminum and brass.

** Total include replacement of components as needed during 20-year period in accordance with Table 2.

Pumping energy

Pumping energy can be easily calculated or estimated by knowing the irrigation requirements, irrigation and pumping efficiencies, and the pumping head

$$PE = K \frac{A\ D\ H}{E_i\ E_p} \qquad (1)$$

where

PE = pumping energy
K = conversion factor depending on the units used
A = area irrigated
D = net depth of irrigation
H = pumping head or the sum of elevation differences, operating pressure, and friction and minor losses
E_i = irrigation efficiency or the percentage of the water applied that is stored in the root zone, expressed as a percentage
E_p = pumping efficiency, expressed as a percentage

Pumping energy can be expressed in any convenient units such as kilocalories per unit area, i.e., Kcal/acre (Kcal/hectare).

The value of the factor K depends on the units of measurements. In this study D is measured in inches (mm), A in acres (hectares), H in feet (m), and PE in Kcal/acre (Kcal/hectare), so that K is equal to 733,400 (233,800). To simplify the computations, the nomograph shown in Figure 3 was developed to estimate the pumping energy from the irrigation requirements, irrigation and pumping efficiencies, and the pumping head. For example, if D = 20 inches (508 mm), E_i = 40%, E_p = 60%, and H = 120 feet (36.6 m), then following the dotted line shown on the figure, the required pumping energy would be 733 x 10^3 Kcal/acre (1811 x 10^3 Kcal/hectare).

Furthermore, pumping energy can be obtained in other units by simply drawing a horizontal line from the point 733 x 10^3 Kcal/acre to intersect the remaining scales which give a pumping energy of 3070 x 10^3 Kjoule/acre (7675 x 10^3 Kjoule/hectare), 80 gallons of diesel/acre (720 liters/hectare), and 850 KWH/acre (2125 KWH/hectare)[5]. In converting diesel fuel into mechanical energy, an energy conversion efficiency of 25% was assumed.

Pumping energy is a function of the volume of pumped irrigation water and the type of irrigation system as well as the elevation difference between the water source and the field irrigation (see Eq. 1). The net volume of irrigation water needed is independent of the type of irrigation system used, but the gross volume of water that must be pumped or delivered is a function of the irrigation efficiency which, in turn, depends on the irrigation system. Generally speaking, the efficiency of simple surface irrigation systems varies between 30 to 70% with 50% as an average value. However, an efficiency of about 85% can be obtained by using an Irrigation Runoff Recovery System, IRRS. Sprinkle irrigation efficiencies vary between 60 and 90% with an average of 70%. The efficiency of trickle irrigation systems varies from 75 to 95% with an average of about 80%.

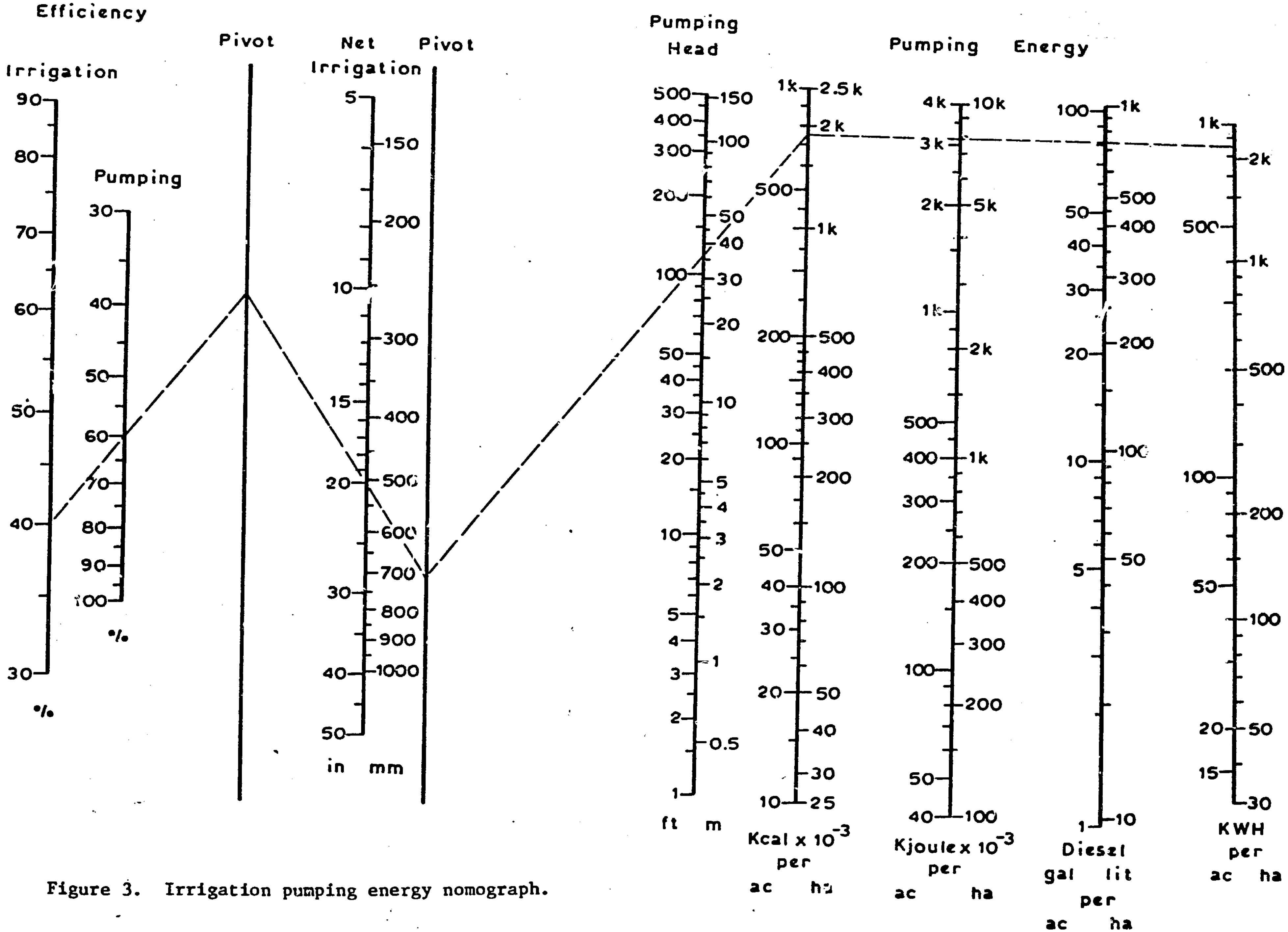

Figure 3. Irrigation pumping energy nomograph.

The operating pressure required at the pump discharge is also a function of the type of irrigation system. With surface irrigation systems where open ditches are used to distribute the water, the pumping head will simply be equal to the water lift plus any friction head loss in the piping. For sprinkle irrigation an average system inlet head of 162 feet (40.4 m) and for trickle irrigation an average working head of 90 feet (27.5 m) were assumed. The above average values for the system inlet head and a pumping efficiency of 75% were used in Eq. 1 to compute the pumping energy as a function of water lift. Figure 4 shows the general variation of the pumping energy per acre-foot (cubic meter) with the water lift and indicates that for water lifts of less than about 50 feet (15.2 m) surface irrigation systems without IRRS would have the least pumping energy consumption. However, for water lifts greater than 50 feet (15.2 m) surface irrigation with IRRS requires the least pumping energy.

Trickle systems require less pumping energy than sprinkle systems for all water lifts. For water lifts above 400 feet (122.0 m) surface systems without IRRS require the highest pumping energy. This is mainly due to the comparatively low irrigation efficiencies and high water losses associated with such systems. On the other hand, if an IRRS is utilized then the water losses can be minimized or eliminated and in this case the pumping energy required will be the least even for high water lifts.

For the specific field considered in this study, the annual pumping energy per acre (hectare) was calculated for the nine irrigation systems presented earlier, using 36-inch (915-mm) net irrigation requirement and irrigation efficiencies as shown in Table 1, a pumping efficiency of 75% and assuming zero water lift, i.e., the water is available at the surface in the well in Figure 2. The results of these calculations are shown in Table 4 together with the installation, labor, and total annual energy inputs. Figure 5 shows the effect of the initial pumping lift on the relative energy inputs for the nine systems studied.

Summary and Conclusions

The results of this particular study indicate that the installation energy requirements are by no means negligible compared to the energy requirements for pumping. Ratios of installation energy to pumping energy vary from a high of 5.0 for surface with IRRS to a low of 0.18 for traveler sprinkle. We point out that pumping energies are mechanical energies whereas installation energies are mainly expressed in forms of thermal energy. It is interesting to note than even though the installation energy for surface irrigation system with IRRS is 1.50 times that of hand-moved sprinkle, surface irrigation is more efficient from a total energy standpoint.

Total energy inputs to the traveler sprinkle exceeds that of the other systems considered because of the high pressure and consequently large pumping energy requirements.

The high pumping energy required combined with a relatively smaller net irrigated area result in a greater total energy input to the center-pivot sprinkle system than to the trickle system even though the installation energy requirements of the trickle system are larger.

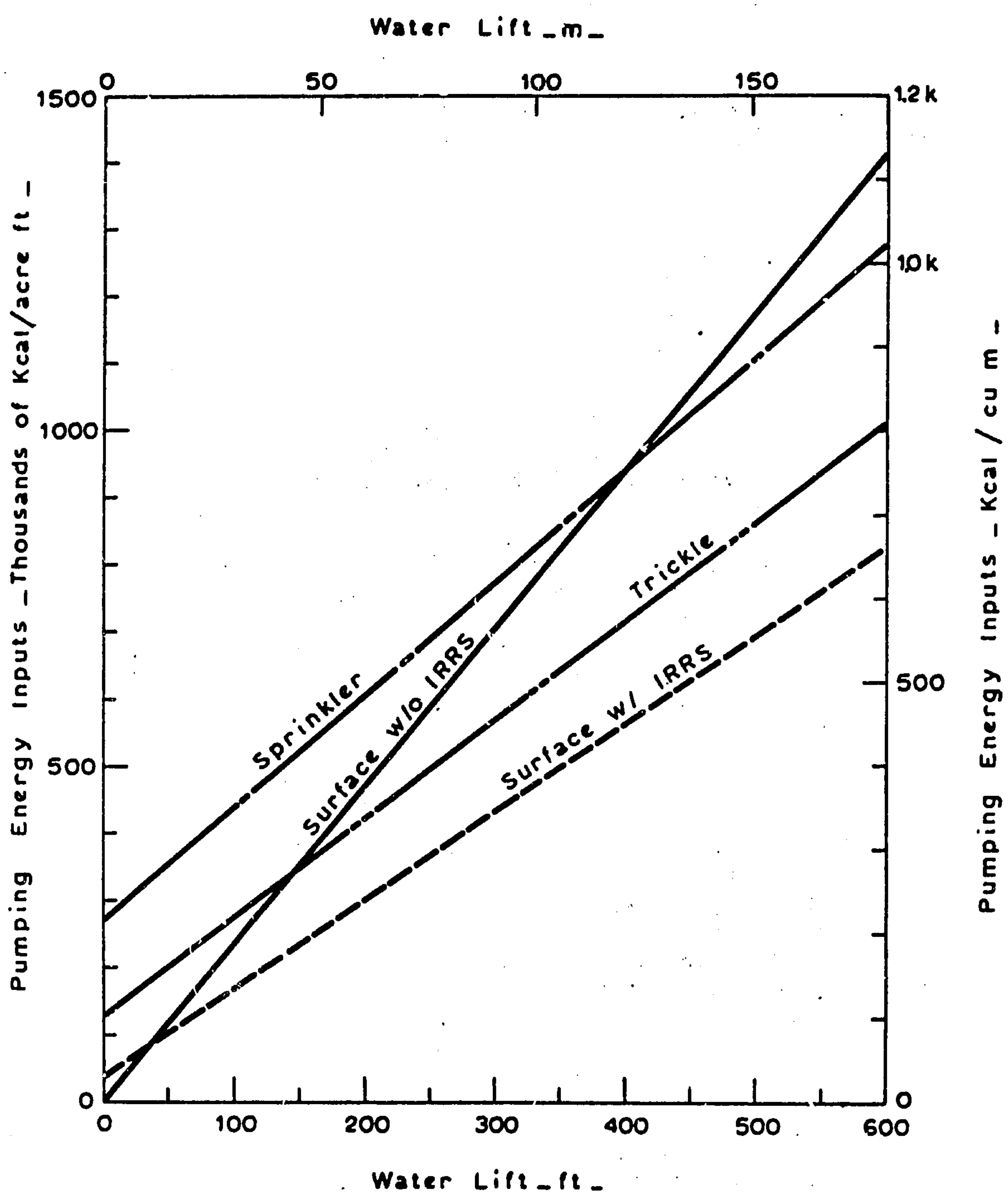

Figure 4. Average pumping energy required for surface, sprinkle, and trickle irrigation systems with different water lifts.

Table 4. Total annual energy inputs in thousands of Kcal (or gallons of diesel) per acre irrigated for the nine irrigation systems based on 36-inch (915-mm) net irrigation requirement and zero pumping lift.

Irrigation System	Installation Energy *	Pumping Energy	Inst./Pump. Energy Ratio	Labor Energy	Total Energy	
Surface w/o IRRS	161.7	34.8	4.60	0.50	197.0	(21.4)
Surface w/ IRRS	242.1	48.0	5.00	0.30	290.4	(31.5)
Solid-set Sprinkle	614.1	770.0	0.80	0.40	1384.0	(150.0)
Permanent Sprinkle	493.6	770.0	0.64	0.10	1263.7	(137.0)
Hand-moved Sprinkle	159.7	804.0	0.20	4.80	968.5	(104.6)
Side-roll Sprinkle	200.3	804.0	0.25	2.40	1007.1	(109.0)
Center-pivot Sprinkle	388.5	864.0	0.45	0.10	1252.6	(136.0)
Traveler Sprinkle	288.9	1569.0	0.18	0.40	1858.0	(201.5)
Trickle	530.5	468.0	1.13	0.10	998.6	(108.0)

* Installation energy is increased by 3% to include maintenance energy for all systems except for solid-set where 1% was used.

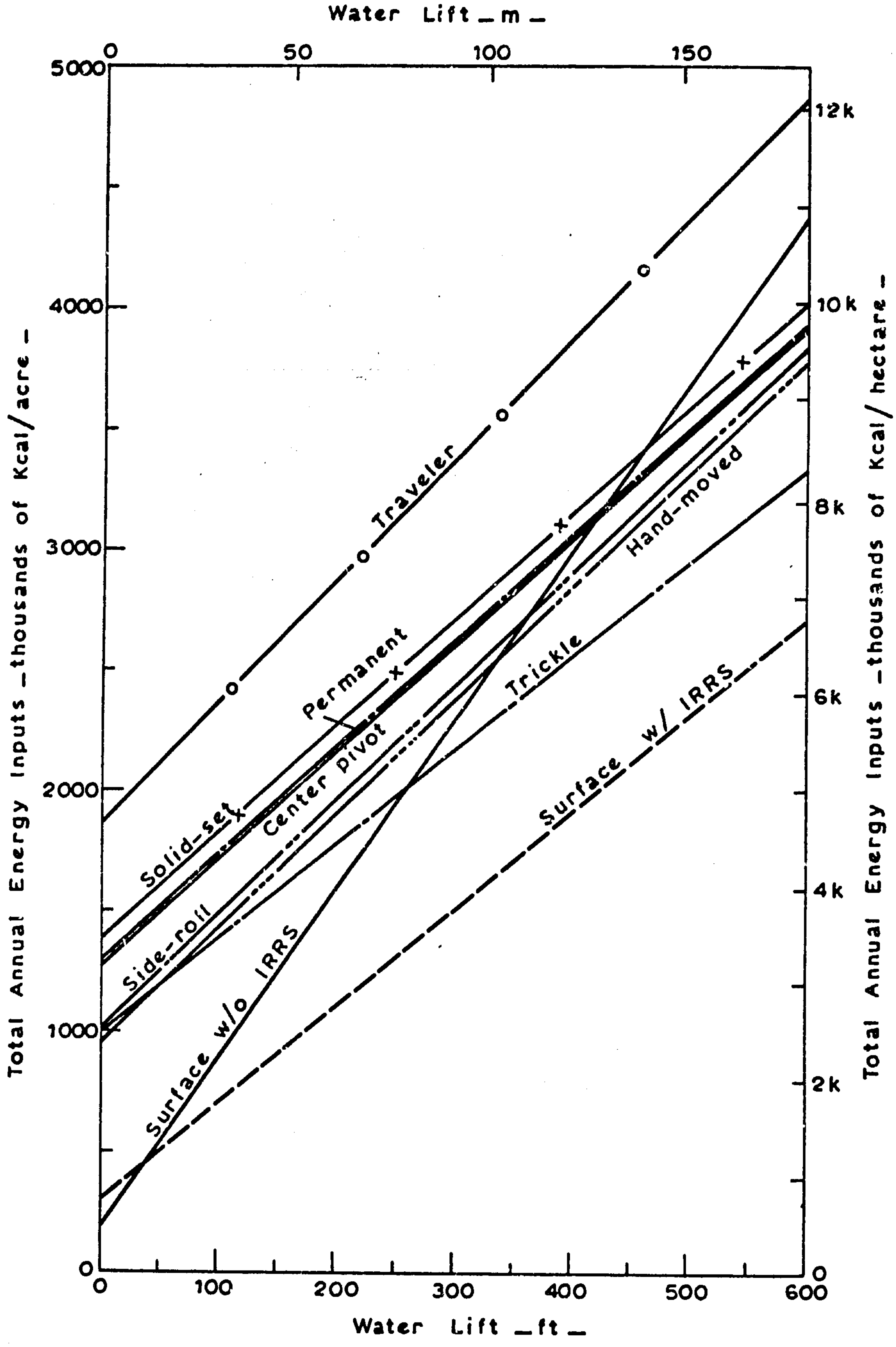

Figure 5. Total annual energy inputs per acre (hectare) irrigated for the nine irrigation systems studied as a function of water lifts, based upon 36-inch (915-mm) net irrigation requirement.

For the particular example presented here, surface irrigation appears to be far more energy conservative than either sprinkle or trickle systems. It should be mentioned, however, that very large water savings are offered by trickle irrigation during the establishment of tree crops or where the crops only occupy a portion of the land surface. Under these circumstances along with high water lifts, trickle and sprinkle irrigation may be more energy conservative than surface irrigation.

Furthermore, where water is in short supply or is only available at a high energy cost such as from a desalinization plant or expensive water supply projects, the energy conservation associated with high water use efficiency in any type of system may outweigh all other energy inputs.

Appendix I. Energy Inputs in Installation

A number of studies regarding the energy inputs to manufactured products have been reported in the literature. Representative figures for major products used in irrigation systems are tabulated below.

Product†	Energy Input in millions of Kcal/ton						Used in this Study
	Ref 2	Ref 6*	Ref 9	Ref 10	Ref 12	Ref 15	
Steel	11.8	19.0	6.6	6.6		17.0	17.0
Aluminum	56.6	112.0	40.0	15.3		60.0	60.0
Brass		65.0		34.7		1.7	34.0
Copper-drawn							60.0
Plastic-Polyethylene	37.7	33.0				1.25	35.0
Plastic-PVC	25.9				21.4		26.0

†It is not clear in every case whether the product is in the form of molten primary material or in a finished form, or whether the energy associated with mining was included. If, for example, brass fittings are made from recycled automobile radiators the energy inputs may be substantially less than if made from virgin material. This may partially account for the lack of consistency among the data from different sources.

*Reference 6 presents data in terms of energy per dollar of demand. The values in Ref-6 column were then obtained by multiplying the energy per dollar of demand by the estimated cost of the product, and should, therefore, be regarded as only an approximation.

A pumping unit consisting of a diesel engine, pump, and control panel was assumed to require about 10^6 Kcal per hp. This compares with 2.65 x

10^6 Kcal per hp estimated for tractor manufacture[15], 0.5×10^6 Kcal per hp for automobiles estimated from data given by Berry and Fels[1], and also correlates with Hannon's data[6].

Electric motors of one-hp capacity were assumed to require about 0.5×10^6 Kcal for manufacture. This is considerably more than the value given by Steinhart and Steinhard[15] but correlates well with the data given by Hannon[6].

The earth moving equipment was assumed to be a 300-hp tractor-scraper unit weighing 55,000 lbs, capable of moving 230 cu yds, and burning 11 gallons of diesel per hour.

The machine to "plow-in-pipe" was assumed to be a 275-hp crawler-tractor weighing 51,000 lbs with an additional 25,000 lbs of equipment, capable of laying 1000 ft of pipe, and burning 10 gallons of deisel per hour.

The trenching unit was assumed to be a 60-hp wheel-tractor with 3000 lbs of additional equipment, capable of digging 80 ft of trench, while burning 1 gallon of diesel per hour.

Each of the above was assumed to have a depreciated life of 10,000 hours so that the manufacturing energy for these units was computed as follows:

$$(\text{hp} \times 2.65 \times 10^6 \frac{\text{Kcal}}{\text{hp}} + \text{Equipment Wt.} \times 17 \times 10^6 \frac{\text{Kcal}}{\text{ton}}) \times \frac{\text{hours on job}}{10{,}000}$$

The energy associated with fuel consumption was computed directly on the basis of 36,000 Kcal/gallon[5].

The energy associated with the labor for system management was based on the number of man-hours required per person; for example, the side-roll sprinkle system would require:

$$44 \frac{\text{moves}}{\text{lateral}} \times 0.5 \frac{\text{hour}}{\text{move}} \times 6 \frac{\text{laterals}}{\text{irrigation}} \times 10 \text{ irrigations} \times 300 \frac{\text{Kcal}}{\text{man-hour}}$$

$$\times \frac{1}{160 \text{ acres}} = 2.4 \times 10^3 \text{ Kcal/acre}$$

A similar procedure for the other systems would yield the following: Surface irrigation system w/o IRRS would require 0.5×10^3 Kcal/acre and w/ IRRS, 0.3×10^3 Kcal/acre. The various sprinkle irrigation systems would require labor energy inputs of 4.8×10^3 Kcal/acre for hand-moved; 0.4×10^3 Kcal/acre for solid-set and big-gun traveler; 0.1×10^3 Kcal/acre for center-pivot and permanent sprinkle systems. The trickle irrigation system would also require only 0.1×10^3 Kcal/acre.

Appendix II. Systems Layout

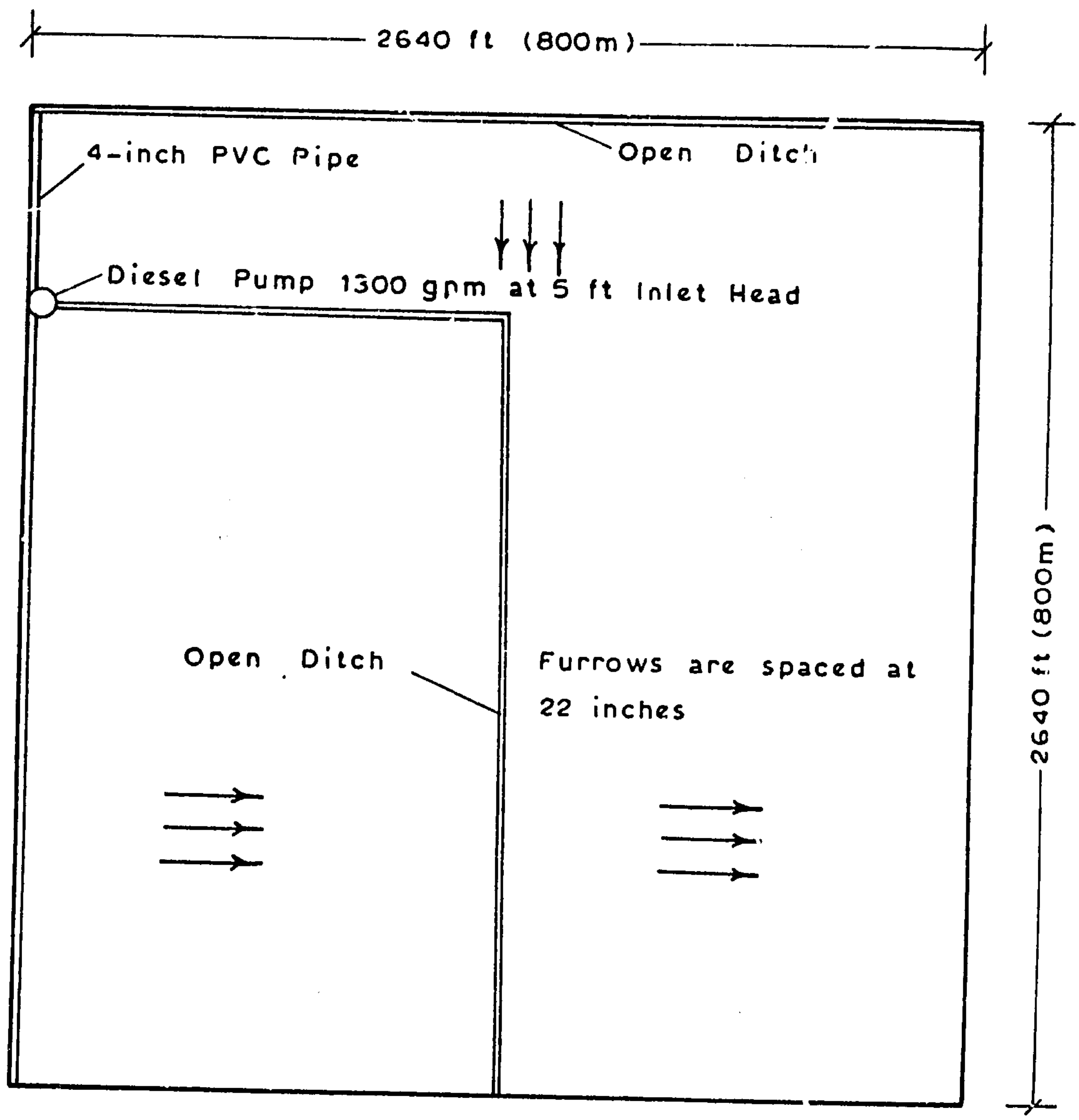

Figure 6. Layout of surface irrigation system using an open-ditch distribution network (suitable for any type of crop).

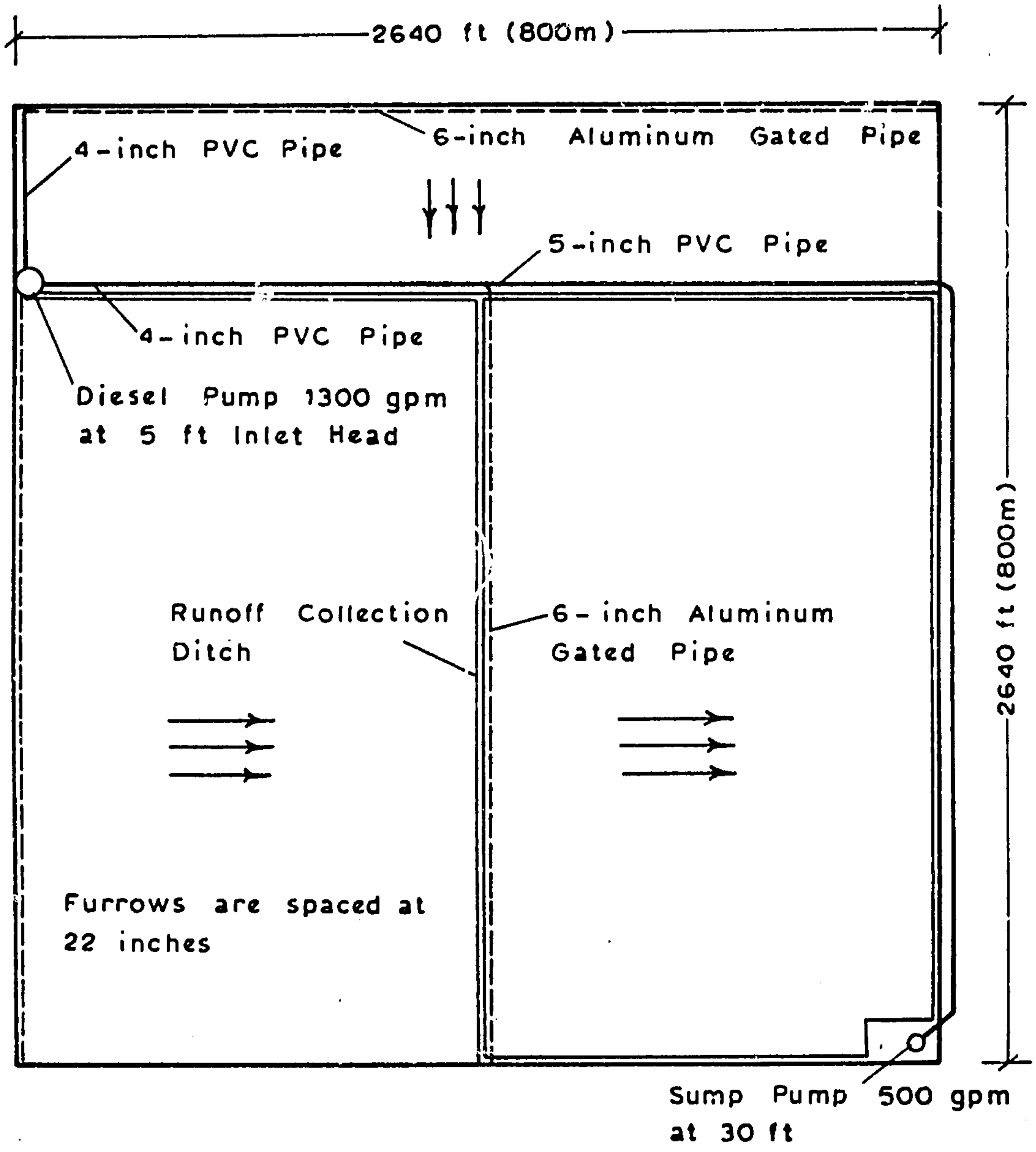

Figure 7. Layout of surface irrigation system using a gated-pipe distribution network and an Irrigation Runoff Recovery System, IRRS (suitable for any type of crop).

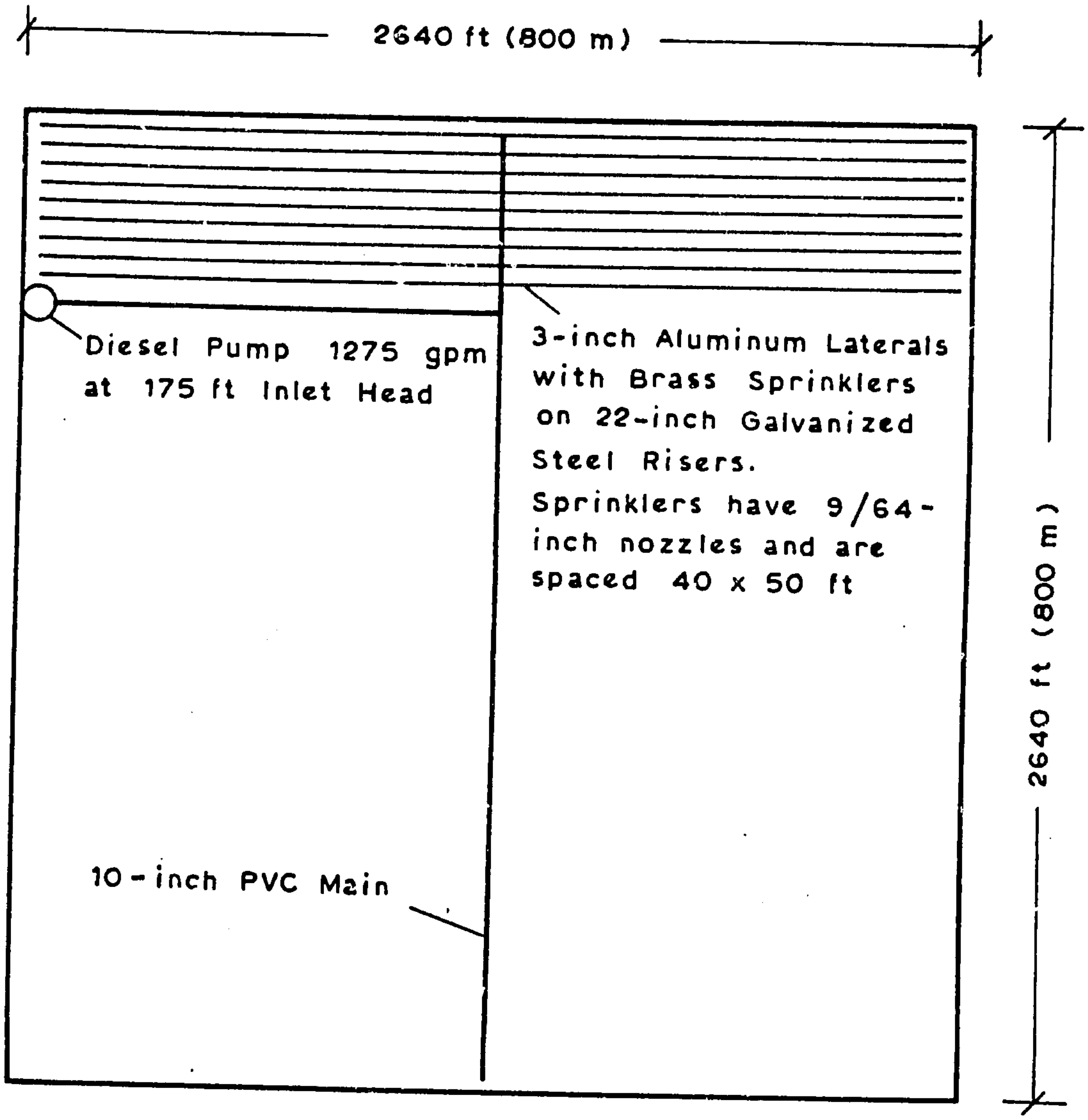

Figure 8. Layout of solid-set sprinkle irrigation system (suitable for any type of crop).

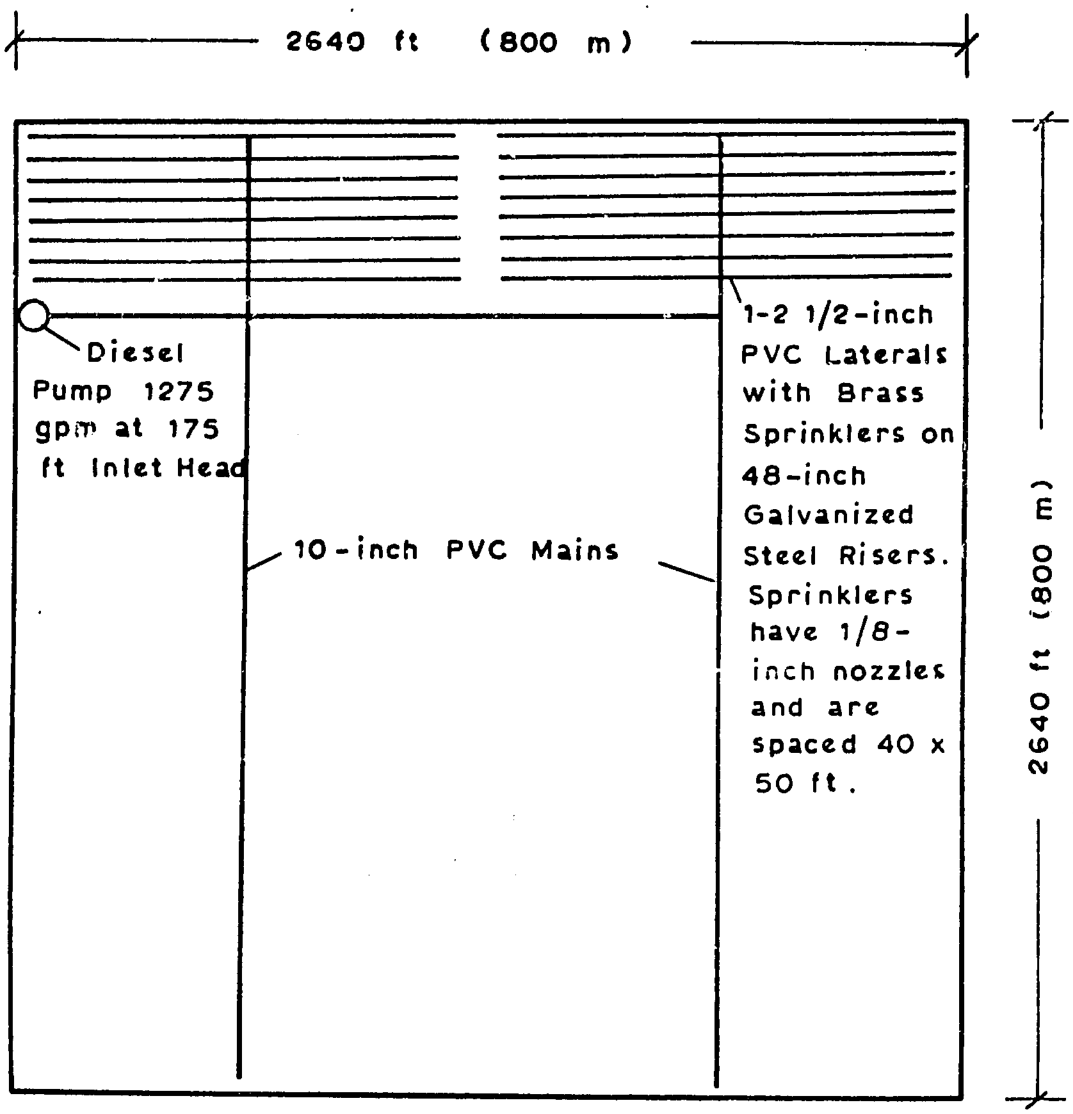

Figure 9. Layout of burried permanent sprinkle irrigation system (suitable for any type of crop).

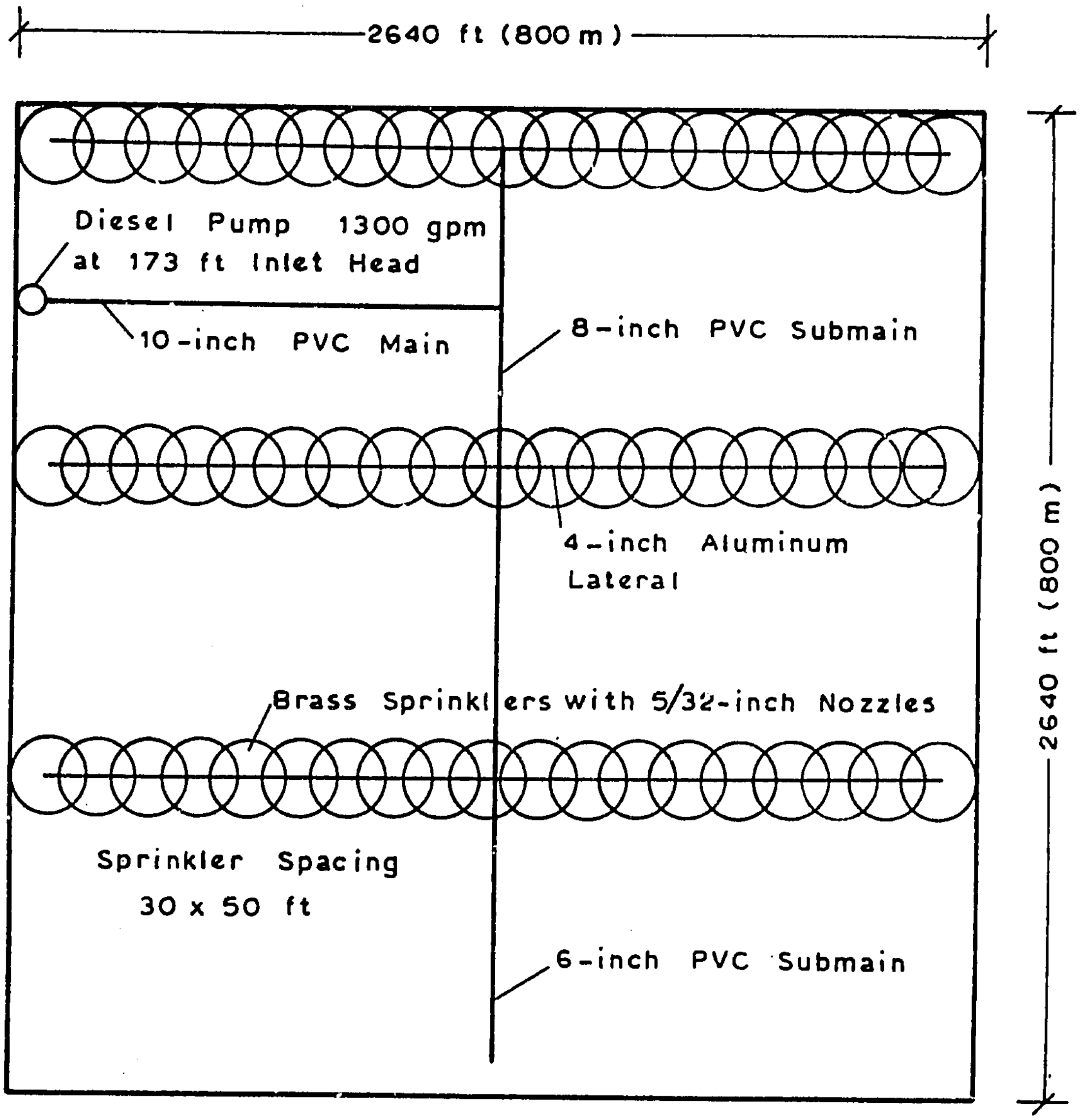

Figure 10. Layout of hand-moved sprinkle irrigation system (suitable for any type of crop) or side-roll sprinkle irrigation system (suitable for low crops).

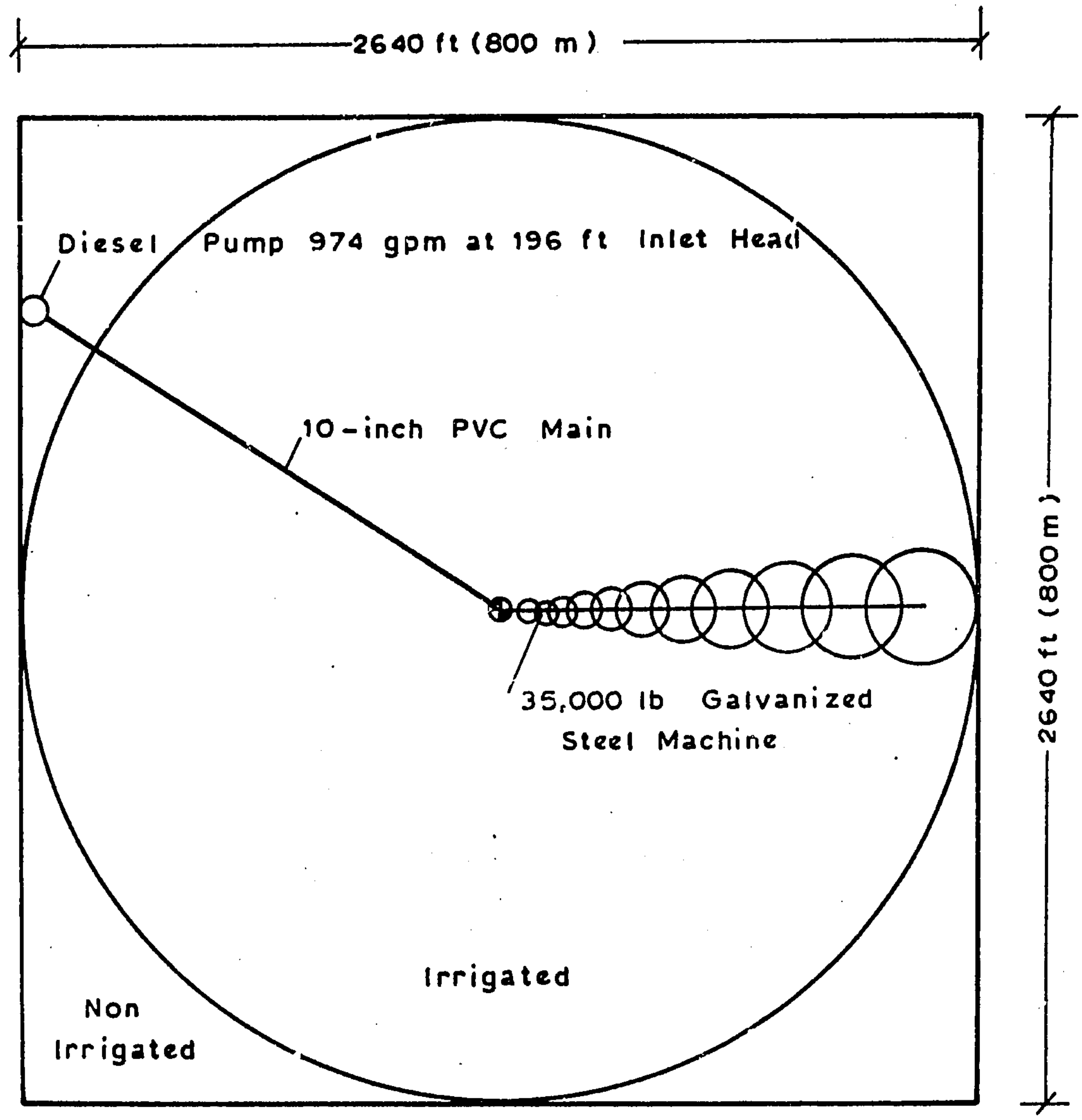

Figure 11. Layout of center-pivot sprinkle irrigation system (suitable for low crops).

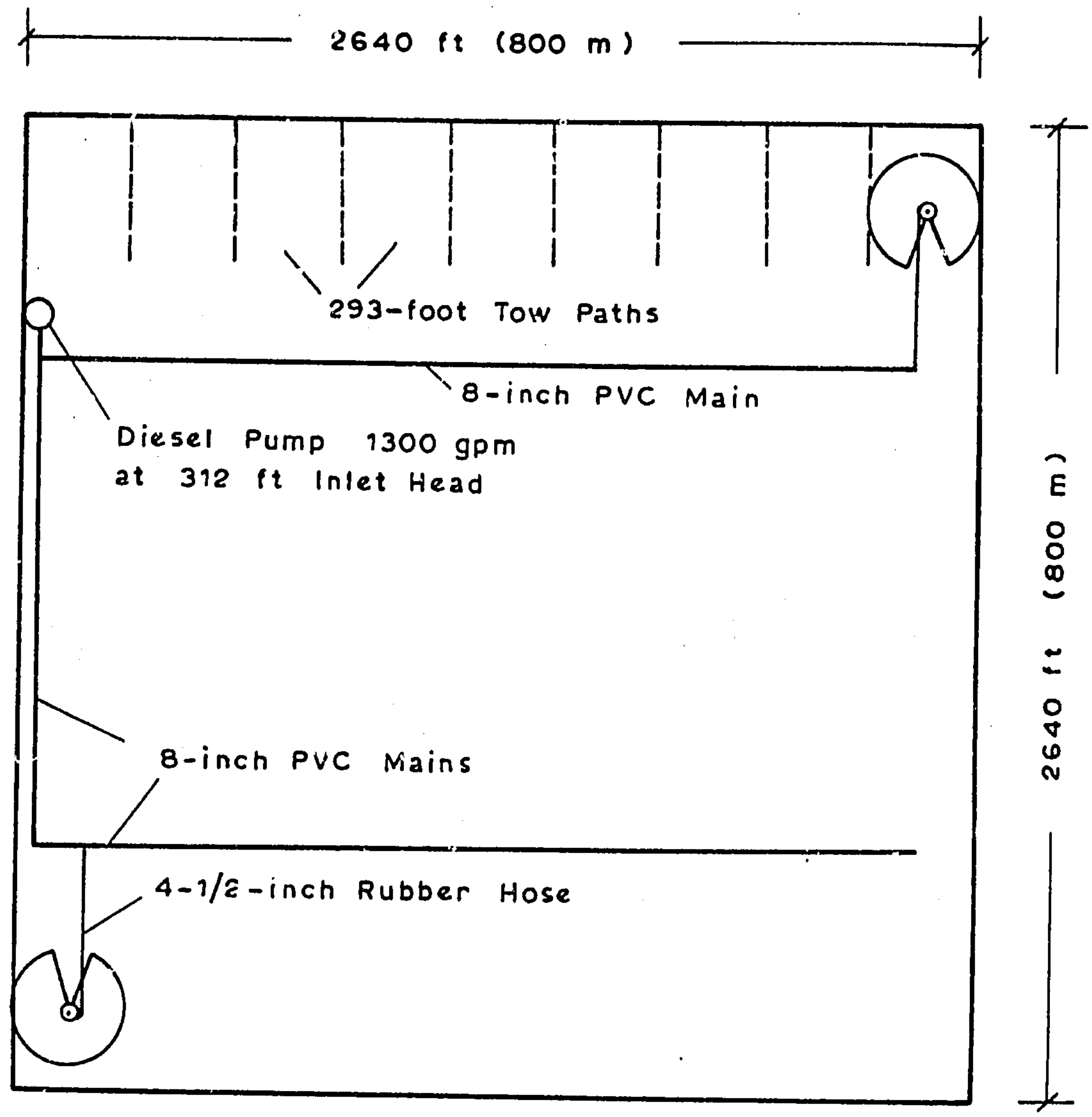

Figure 12. Layout of big-gun traveler sprinkle irrigation system (suitable for any type of crop).

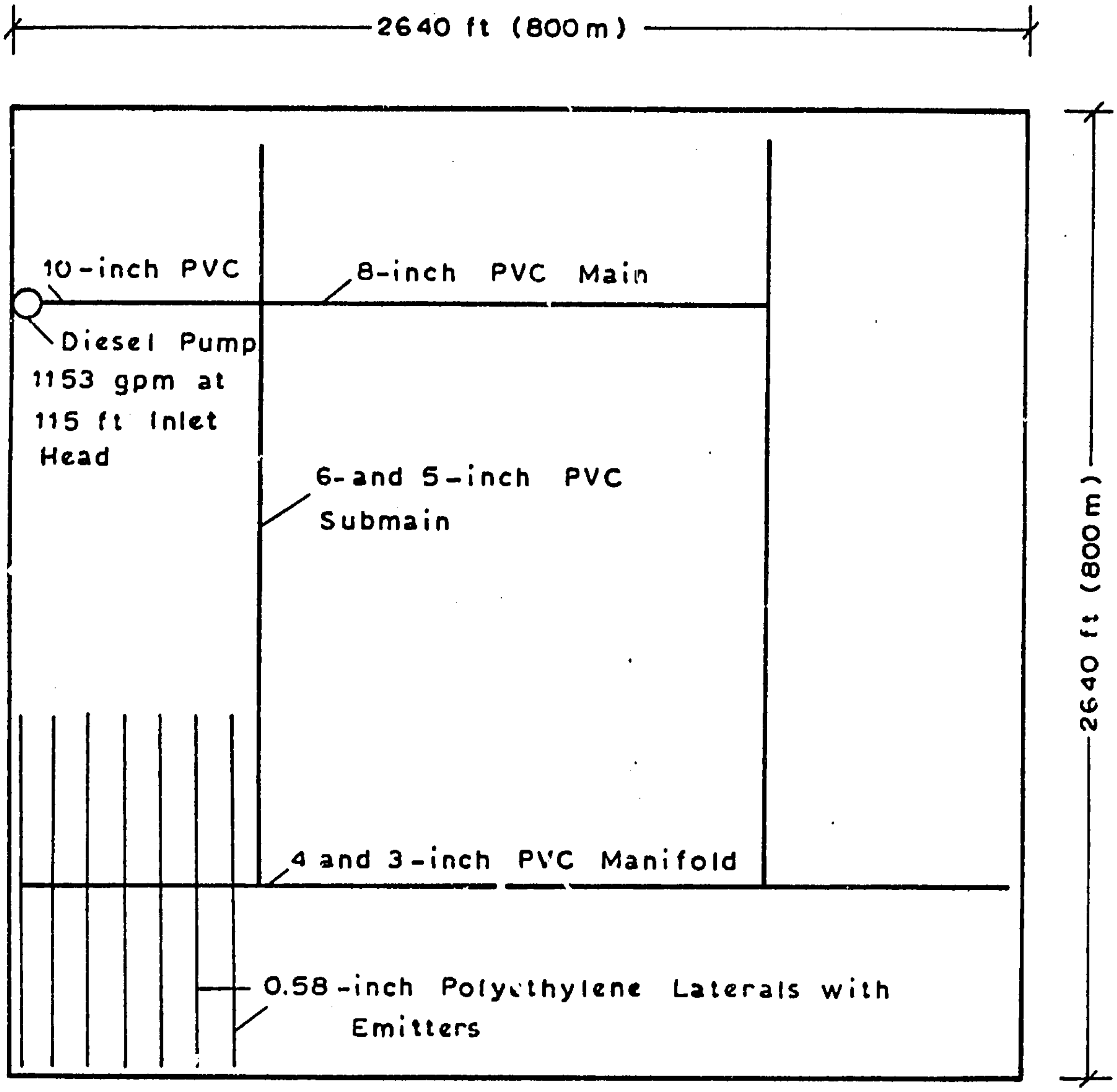

Figure 13. Layout of trickle irrigation system (suitable for permanent tree crops).

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