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ANALYSIS OF ENERGY DEMAND IN IRRIGATION SYSTEMS

by

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Research Guide

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1. INTRODUCTION

All over the world efforts are being concentrated for modernization of agriculture in the pursuit of increasing food and fibre production. Application of modern technology to grow up the specific yields and steady increase of technical level of production to reduce the labour requirement demands the industrial originated materials and equipments i.e. chemicals, energy sources, machines and buildings in rapidly growing extent. Although the agricultural sector, in general, is not an energy intensive production line, the adoption of most up-to-date technologies in plant production and animal husbandry require at present some 4 to 5 times more energy than twenty years ago. In spite of serious energy saving programmes, for the sake of further increase of agricultural productivity the direct and total energy demand of agriculture will grow in the future, too. In some parts of the world irrigation is an indispensable element of farming and above a certain level of specific yield most of crops need irrigation even in moderate climatic zones.

As regards the energy requirement of irrigation - depending upon the water requirement and applied methods of irrigation - is especially energy demanding agricultural operation. The chief sources of energy for irrigation in most of countries are fossil fuels and electricity. As the oil shortage and prices of all sorts of energy are escalating from year to year it is important that the energy consumption in existing irrigation units and of the more developed irrigation plants to be designed in the future, should be as efficient as possible. According to the expectable irrigation development tendency, the installation of more and more large irrigation pumping units sooner or later is inevitable all over the world.

It has been observed that due to certain technical reasons and advantages the use of electric energy for irrigation is becoming more popular. Electric energy is really an effective

source of energy, its application makes possible to reduce the labour requirement, to adopt automatic control systems and remote operation of machines and units, but simultaneously electricity is the most expensive source of energy

The further intensive development of agricultural production depends considerably upon the permanent extension of energy intensive farm irrigation. Among the present and future conditions, when the energy shortage and increasing of energy cost has become a predominant factor of national and international economy, the detailed analysis of irrigation energy demand discovering of most important relationships for reduction of specific energy and energy cost demand for irrigation has become one of the most immediate task of agricultural engineers and economists. This fact has been proved by the great number of studies, investigations, papers and thesis dealing with different aspects of this subjects.

1.1 National and international importance of the subject

In the modern world we are facing an increasing shortage of food, energy and water. Food shortage can be eliminated for example by development of irrigated plant production, however it needs both increasing amount of water and energy. For long-term irrigation development the availability of water, investment funds and growing cost of energy are the basic limiting factors. Many irrigationists have been motivated to develop and operate irrigation systems to improve water utilization but until recently energy conservation was not a major consideration.

The solving of above mentioned contradiction and creating the necessary conditions for harmonious progress in this field is an important part of national development policy. This is especially essential in developing countries e.g. in India where the food shortage is serious and, in those developed countries, e.g. in Hungary, where the export of surplus food stocks is significant source of national economy.

In Hungary, the irrigation of arable land and horticultural crops has become important since early sixties, mainly for

increasing the specific yields and to compensate the natural rainfall in droughty years. The total irrigation capacity, at present, is about 480 thousand hectares, some 10 per cent of cultivated area /Appendix 1.1/. About 180 thousand hectares of irrigated land is supplied by technical equipments and some 45 per cent of which is installed with underground pipe-line networks. Depending on weather conditions about 150 to 320 thousand hectares is actually irrigated /Appendix 1.2/. As regard the break down of irrigated area according to the most important irrigation methods, the share of most energy intensive sprinkler irrigation reaches 70-75 per cent while that of surface irrigation is some 20 per cent and the subsurface irrigation covers only 3-6 percent of actually irrigated area.

The yearly water utilization of irrigation changes between 400 to 800 million m³ depending mainly on weather conditions. The average water application varies from about 220 mm up to 360 mm and within this scope for arable lands between 280-380 mm, for vine and fruit 90-120 mm and for greenfield between 130-190 mm, as a national average in Hungary /Appendix 1.3/. The irrigation pumping capacity in state and cooperative farms and, in hands of water supplying companies can be characterized by the following figures:

	in m ³ /sec
- lifting pumps	235,3
- portable sprinklers' pumps	168,9
- installed sprinklers' pumps	23,2

There is no statistical data for development of installed power capacity of irrigation pumps, but taking the average power requirement of water transport the total capacity of diesel operated pumps can be estimated some 200-220 MW /270-300 thousand HP/, and that of the electrically operated pumps some 35-38 MW. Unfortunately, mainly because of the novelty of investigated subject there is no reliable statistical data for electrical energy and diesel oil utilization for irrigation purposes. Starting from the above mentioned specific and total water utilization and break down of irrigation methods and power sources /Appendix 1.4/

the --

total yearly energy demand of irrigation in Hungary changes between the following limits /Appendix 1.5/:

- electricity 20-30 million kWh/year
- diesel oil 30-40 thousand t/year

The estimation of energy utilization is rendered more difficult also by the fact that the irrigation pumps and machines are operated partly by agricultural and partly by water management sectors, later of which is responsible for supplying water to other branches of national economy, too. In this way at present there is no exact statistical data for actual energy utilization of agricultural water supply and irrigation. During last years the direct energy utilization of state and cooperative farms for irrigation purposes excluding water lifting and feeding of irrigation canals etc. varied between 10 to 12 million kWh and 7 to 13 thousand tons of diesel oil per year, while that of used by water management companies varied between 15-18 million kWh and 25-32 thousand tons of diesel oil including also the energy demand of primary and secondary lifting of water.

Based on calculated energy requirement of irrigation and taking into consideration the rapidly growing average price of different sources of energy, also in Hungary, the total cost of direct energy demand for irrigation purposes, during the last years has been changed in the following range:

- electricity 25-40 million Ft/year
- diesel oil 135-180 million Ft/year

According to the long term irrigation development programmes the irrigation capacity will be doubled within twenty years, the actually irrigated land may reach some 600 to 700 thousand ha in droughty years which means that the long-term electric energy requirement of irrigation will be about 60-70 million kWh and the diesel-oil requirement some 70-80 thousand tons, assuming 1200-1300 million m³ irrigation water demand at that time and further increasing role of electrically operated high pressure sprinkler irrigation systems.

The irrigation, in general, and especially the high pressure systems demands significant amount of energy i.e. some 0,3 - 0,4 kWh/m³ and 0,10-0,15 kg/m³ for electrically and diesel oil operated pumps, respectively. Among average Hungarian climatic conditions we need about 180 to 240 mm water application which means that the specific energy requirement of irrigation varies between 540 to 960 kWh/ha and 180-360 kg/ha for electrically and diesel oil operated sprinkler irrigation systems, respectively. From the analysis of energy demand of non-irrigated plant production it is known that for example for corn production systems, having very high level of mechanization we need some 80-90 kg/ha of diesel oil consumption and 45-65 kWh/ha of electric energy consumption. It is clear even from these data that energy demand of sprinkler irrigation is two to three times more than the total energy requirement of dry-land production.

The national importance, of selected subject of investigation is beyond discussion because the total electric and diesel oil energy demand of irrigation even nowadays is significant compared to total demand of agricultural production and this ratio will grow in the future. Further, the steady increase of specific energy costs may endanger the economics of irrigated plant-production but on the other hand irrigation is an essential precondition for reasonable enlarging of specific yields. And finally as the specific energy requirement of irrigation per hectare of land is many times higher than all energy demand of other production processes, the optimal level of energy content of agricultural products depends basically on exploitation of energy used for irrigation purposes. On the basis of planned investigations the reasonable level of energy and energy cost of irrigation, the possible ways of energy savings of existing irrigation plants and more reasonable constructions and systems of future irrigation practice can be formulated.

1.2 Irrigation energy implication for India

India has predominantly agricultural economy and about 70 percent of the populations' survival depend on agriculture. India has more unused agricultural potential /land, water and energy/ than any other country of its size. It is estimated that if certain guide lines are strictly followed it would be possible to ultimately irrigate about 110 million hectares, that is 52 percent of the gross sown area of 210 million hectares. The country has a huge population to support, adding about 10,8 million mouths every year. The population growth by 2000 is expected to reach about 800 million with a projected demand of 260 million tonnes of food grain. As a result of irrigation development which now covers about 25 percent of the cropped area, the production of food grain is becoming more stable. Now about half of the total production comes from irrigated areas. Irrigation development has also proved to be an employment generating activity, as irrigated farming demands more labour-man days. Thus irrigation plays a very important role in countrys' socio-economic life.

At the beginning of the first five year plan /1951-1956/ the area under irrigation was 9,7 million hectares for major and medium projects and 12,95 million hectares for ground water and minor surface water schemes. While in the year 1978 some 24,9 million hectares were irrigated by major and medium schemes and 27,3 million hectares on account of ground'water and minor irrigation sources. In the sixth five year plan /1978-83/ additional potential of 17 million hectares has been planned, out of which 8 million hectares through major and medium projects.

During earlier times the entire irrigation has been possible by gravity flows. But recently the development by pumping from surface sources /river, canal, lake, reservoir/ and under ground water sources /dugwells and tubewells/, has received an ampetus. Adoption of modern production technologies by farmers have been proved to increase the value of output per hectare. However without an assured supply of irrigation water, farmers are getting discouraged to apply the expensive modern technology.

Water source coupled with a pumping unit supposed to provide a secured water supply to the crop and therefore pumped irrigation is becoming widespread. Pumped irrigation in India could be categorized in two types:

- lift irrigation schemes and,
- on farm pumping.

The lift irrigation from rivers has been rapidly expanding to cover many areas which were drought-prone and backward. The new techniques of large-scale pumping from rivers is being developed through installation of floating pumping-sets. In addition, permanent pumping stations of various capacity have been constructed throughout the country on some canal systems and reservoirs behind the dams and barrages to cover the areas which were earlier considered inaccessible for the gravity irrigation.

As regards on farm pumping schemes which are minor irrigation units, intended to increase an utilization of ground water potential for agricultural purposes. This system has given a boost to install pumping-sets by individual farmers. Those farmers having either the source of surface water or ground water available near or in his field installs diesel or electrically operated pumping-sets ranging from 5 HP to 15 HP /3,5 to 11 kW/ for irrigating his area ranging from 1 ha to 50 ha. The water delivered is then applied mostly by gravity irrigation methods /furrow, border, basin etc./ or in limited and special conditions by sprinkler method. Drip irrigation is still in experimental stage. With intensification of rural electrification and availability of institutional finance to the farmers, the dugwells and pumpsets have become very popular and their numbers have increased very fast /Appendix 1.6/.

The irrigation is a major consumer of commercial energy sources also in India. The conventional energy sources available for lifting irrigation water are, human and animal power, diesel fuel and electricity. While non-conventional energy sources

which have shown some potential for their application in irrigation pumping are, solar-energy, wind-power and bio-gas energy. However practical application of these non conventional resources of energy is very limited at present stage owing to the prohibitive installation costs. Thus the conventional sources of energy remain to be the most commonly used source at present and in the near future, too.

The unit cost of lifting water by traditional devices has been estimated to range from Rs. 5,91 to Rs. 13,14 per acre inch/0,57-1,27 Rs/mm/. The corresponding cost of modern methods for lifting water have been derived to range from Rs. 3,1 to Rs. 4,45 per acre inch/0,30-0,43 Rs/mm/.

During the past few years energisation of large number of pumpsets through Rural Electrification programme has been boosted up. While in 1956 only 56 053 pumpsets were energised till 1977 this figure grew up to 3,136.220. The number of electric motors, in 1977, were 16 times more and diesel engines 4 times more than in 1961. However there was hardly any net addition to the number of traditional water lifts during the same time. Thus the on farm pumping demands high proportion of total energy supply for irrigation and it needs careful considerations.

As far as diesel oil supply is concerned, there occurs frequent continual shortages and prices are continually rising. So farmers are unable to run their engines due to shortage of diesel oil and crop yields are affected. Farmers have thus stepped up their demands for electric connection for tube wells which are at present run with diesel engines. However electricity supply, provided from hydro and thermal power stations has been characterized by frequent break-downs and shortages. Especially in low rainfall years owing to low water level in dams substantially resulting in power cut to industrial sector and limited power supply to irrigation pumps. Thus it becomes very critical to utilize the available energy supply at most efficient way during low rainfall years when crops are in great need of secured and enough water for optimum yields,

In conclusion it can be stated that the task before indian irrigationists is twofold:

- increasing the water use efficiency i.e. to increase the yields per unit of water created for irrigation, by using the available irrigation water as judiciously as possible; and
- improving the "energy use efficiency" of irrigation, i.e. to increase the output of crops per unit of input energy by reducing the specific energy demand and cost of irrigation.

1.3 General objectives of investigations

Irrigation, in general, is a thousand years old practice in agricultural production, but during the last 40-50 years parallel with the technical development of intensive farming enormous research activity has emerged in order to put into practice more and more effective technical solutions of irrigation, to determine the optimal level and methods of water application and to evaluate its economics. In the last few years when world has to face the danger of drastic shortage of food, energy and water, the economics of food production has become one of the most important consideration of agricultural development policy. Consequently, a new line of irrigation research activity has been developed, which is concentrated to the energy and energy cost relationships of irrigation. The energy and energy cost analysis of irrigation includes technical, agronomical and economical points, too, thus the research programme carried out on this field should be an interdisciplinary one.

The study of energy relationships of farm irrigation in general, is unambiguously substantial. Nevertheless, because of the wide - spreading scientific work on this field all over the world and in consequence of special characteristics of irrigation energy economy, it is very important to define the exact subject and concrete objectives of my own research program, execution of which may result in really new scientific

issues for further technical developments of irrigation establishments and for more reasonable operation of existing ones.

The basic objective of my present research programme is to deal with evaluation of pumping energy requirement and related energy costs of irrigation in general, and with energy utilization efficiency of large-scale semi-permanent sprinkler irrigation units in particular, where the means of automatic control may also help to reduce the energy and water demands.

The detailed and specific objectives of my present study are, as follows:

- to evaluate the related literature concerning both energy demand and energy losses of irrigation;
- to carry out pertinent field experiments in large-scale semi-permanent sprinkler irrigation units;
- to develop pumping energy computer simulation models for determination of basic relationships;
- to make suggestions for the possible ways of energy savings in irrigation design and practice.

The detailed study of irrigation energy implication has come in to vogue since the development of oil crisis. From that time many investigators have focussed their attention to analyse the complex process of energy consumption in irrigation and to find out some possible ways of energy savings. It can be observed that the approach of these investigations varied from country to country depending on the level of mechanization, climatic situation, quality and quantity of water available for irrigation etc.

Thus one of the objective of my special interest was to arrange systematically the available literature and to project the clear view of energy interpretation in irrigation process.

As regards my own research activities, starting from the available statistical data for Hungarian irrigation practices, firstly, the national parameters were analysed, followed by one of the largest irrigation area called Tisza II. project.

The overall energetical data of Szolnoki TRVTV company was examined for the last five years period, and that of the Mezőhék-Tiszaföldvár irrigation plant in more detailed form, based on data collection of five irrigation pumping units. Finally, during 1979 and 1980 irrigation period the Mezőhék I. pumping unit was investigated in full details, applying necessary instruments and special equipments to determine the most important energetical characteristics and relationships of installed sprinkler irrigation units, necessary for further parts of my research programme.

According to the actual and long-term planning data available for different countries, including Hungary, having well developed agricultural production, the area under irrigation, especially under sprinkler, surface and drip irrigation is steadily increasing. Thus the pumped irrigation will be expanding rapidly also in the future, demanding more and more energy for operation. As the specific energy requirement for irrigation is influenced by many factors I intended to develop single computer programmed mathematical model by the help of which the total pumping energy can be simulated starting from water source up to field application. The objective of simulation is to calculate specific energy and energy cost requirement per unit of water applied for different methods of irrigation, for various crops and, operation conditions.

In those countries where modern ways of irrigation have become into general practice, like for instance in Hungary, the semi-permanent sprinkler irrigation system having underground buried mains and submains and mechanically driven laterals is becoming more and more popular due to its low labour requirement and high productivity. The planning of buried pipe line network for large irrigated areas needs special computer programmed designing methods to determine the optimal i.e. most economical, pipe diameters. The applied planning method in Hungary is the "minimum cost design", but because of the energy shortage and increasing cost of energy it is worth to develop also the "minimum energy cost design" method, and

to determine its applying limits, depending on increasing cost of energy sources.

During the last decades the development of irrigation has been characterized by extensive ways, where the increase of water application over large areas is most typical, taking not very seriously into consideration the energy savings and reduction possibilities and energy cost implications. In the future the further spreading of irrigation in some countries up right will be restricted by energy sources and in a given situation by the energy costs.

Thus, my final aim within the framework of this study is to findout energy and water consumption characteristics of large area semi-permanent sprinkler irrigation units, and to discover some possible ways of reducing energy demand and energy cost of irrigation for the present and future establishments.

1.4 The methodology of research programme

The selected subject and general objectives of projected research programme, approved by Scientific Qualifying Committee of Hungarian Academy of Sciences, determines the general and specific characteristics of investigation's methodology. The energy economy of agricultural processes, in general, and the energy economy of farm irrigation, in particular, includes besides the technical problems, economical and agronomical aspects, too. In this way the solving of main objectives of research programme necessitate a manysided approach of the whole subject. The basic problem of my investigations is the analysis of specific energy demand of irrigation which needs, first of all collection of statistical data, and execution of related field experiments. The elaboration of second topic, the analysis of energy and cost implications requires mathematical programming, economical means and proceeding. At the same time the entire investigation should be based on biological functions of different crops and their reasonable demand for water including meteorological, soil and labour organization points of view.

1.4.1 General methodical aspects

The general characteristic of methodology followed on the course of working up of outlined research programme is that on the basis of critical evaluation of related literature and my own research activity the technical-economical parameters representing the examined field of irrigation has been summarized in a system modell. The computerized solution of mathematical modell results in theoretical relationships among the observed characteristics and in principle limits or ranges of examined parameters. By the help of statistical data collection and energetical measurements of electrified installed sprinkler irrigation systems and most important irrigation pumps among field conditions, the basic operation parameters were collected and the theoretical calculations were certified. Finally as a conclusion of theoretical and experimental work the new scientific results have been concluded.

The outlined general methodical aspects were applied for the whole research programme and also for different details of it. As regards for e.g. the elaboration of related literature, because of the great number of references mainly from American and Western European sources I intended to survey only the basic approaches of irrigation energy relations. In consequence of limited extent of my dissertation it was out of my aims to explain the various investigations in detail. The main subjects on which the writing up of connected references were focused are, as follows:

- implication of energy for irrigation development,
- energy demand, and cost of irrigation,
- pumping energy for irrigation,
- possible ways of energy savings in irrigation,
- automatic control for energy saving purposes.

On the basis of review of references in national and international respect I attempted to develop a completed pumping energy simulation modell to determine the specific energy and energy cost indices for the various sources of water and

energy for pumping, including different irrigation methods, water applications, irrigation and water-transport efficiencies etc. Because of the great number of changing elements and variations, computer programming procedure have been used for execution of calculations. The most important results of simulation were further processed and presented in a series of diagrams.

For the sake of field experiment the most up-to-date large-scale sprinkler irrigation system in Hungary was selected belonging to Tisza-II project in Mezőhék-Tiszaföldvár district, having six concentrated pumping units of very high capacities for irrigation of nearly 7500 ha arable land. The irrigation system was build as an experimental establishment for the eighties and nineties supplied with instrumentation and automatic control of high level and in this way proved to be an excellent place for studying the real energy requirement of large irrigation units.

1.4.2 Details of adopted methodology

The detailed methodology of my investigations may be divided into three parts namely, the methods of field experiments, introduced by evaluation of statistical data, method of developing of computer simulation models, and finally the method of drawing up the new scientific results.

As an introduction to field experiments, first of all, the available national data representing the irrigation development in Hungary, expressed by total irrigation capacity, actually irrigated land and its break down according to irrigation methods, the water application and water utilization for different purposes, etc. were collected /Appendix 1.1 to Appendix 1.4/. The accessible energetical data on national level for irrigation pumping capacity and energy utilization of diesel and electrically driven units in agricultural and water management companies, were collected, too /Appendix 1.5/.

More detailed irrigation and energy data was available at the Szolnok TRVVV company which is responsible also for operation of Mezőhék-Tiszaföldvár irrigation system. In order to approach more exactly the real diesel oil and electric energy demand of primary and secondary lifting of water and for supplying of different sorts of irrigation pumps, the total energy consumption of the company for many years and the specific energy consumption of each pumping unit of Mezőhék-Tiszaföldvár irrigation plants were collected from 1978 to 1980 years. /Appendix 3.1 - Appendix 3.6/ Further on going more and more into the technical details of irrigation energy, implications during 1979 and 1980 irrigation season the collection of monthly, weekly and daily energy consumption and water supplying parameters of Mezőhék-Tiszaföldvár irrigation plants were organized and for that purposes the forms represented in Appendix 3.13- Appendix 3.19 were used, filled up by the irrigation technicians. Finally, during the 1980 years' irrigation season at Mezőhék-I. pumping unit I carried out myself a fully detailed measuring programme for determination of irrigation and energy utilization parameters. In order to study the real irrigation practice, I organized the readings of all instruments in every hour, the picking up of exact continuously registred diagrams for water discharge, pressure and electric power demand for the whole period, knowing exactly at which hydrant how many machines and sprinklers were in fact in operation /Appendix 3.27 - Appendix 3.30/.

The great amount of irrigation and energy data from different levels of operation and representing various operation conditions were processed with the adoption of well known methods of mathematical statistics and for this purposes as well as for evaluation of diagrams made by recorders and other instruments, unified computer programs were utilized. The results of data collection and their processing methodology are discussed in detail in Chapter 3.

On the basis of review of the selected references and my own experiences during the course of study, I developed three mathematical models relating to the energy demand and cost aspects of irrigation. The first is the pumping energy demand and energy cost model, suitable to determine the primary and total pumping energy for irrigation, to compare the different irrigation methods from point of specific energy and energy cost requirement, to compare the pumping energy cost of electrically and diesel fuel operated pumping units, to discover the effect of changing irrigation parameters on energy consumption etc. The second model deals with the determination of optimal diameter of pipe sections, involving numerous variations of possible influencing factors as for example yearly operation hours, pipe water discharge, average price of energy, specific head loss, specific price of pipe, pipe diameter etc. The third model was developed for finding out the optimal size of irrigation unit, on the basis of minimum energy design, influenced by a great number of different parameters as e.g. technical and hydraulical factors, irrigation practice and operational characteristics, economical points of view etc.

Because of the great number of different parameters and relationships influencing the energy and energy cost of irrigation various series of equations have been adopted and arranged systematically for realization of general objectives. To carry out the planned calculations, great amount of data and basic parameters had to be processed, which required the adoption of computer programming. For the sake of printing out the most important results in unified table form, the symbols applied in the analysis have been also unified, using three block letters for each parameters. The detailed description of mathematical models, the list of symbols /Appendix 4.1/ and the processing methodology is discussed in Chapter 4.

Since computer programming had to be used for processing of basic data and simulation of different energetical characteristics of irrigation I required the help of Computer Centre of University of Agricultural Sciences in Godbüllö.

The computer used was ODRA 1204 and the computer programs were written in FORTRAN language. The schematic diagrams of modell operation and their mathematical programs are presented in the Chapter 4. where the given subject is discussed.

2. IRRIGATION AND ENERGY

The following literature reviewed from various national and international sources provides a clear apprehension of the irrigation and energy. Analysing the role of energy in irrigation processes and its interrelation with other elements of irrigation consists of understanding its implication for present and future irrigation development. Studying the energy inputs, energy demands and costs for various irrigation systems and possible energy saving ways discovered in different regions of the world could be a good introduction and solid basement of my own research activity on this field. Starting from results of related scientific research programmes the importance of energy implications of irrigation will be expressed.

2.1 Implication of energy for irrigation

CHANCELLOR and GOSS /1/ stated that in the structurally transformed agriculture, out of the total energy requirements for farming and farm inputs for non irrigated grain production, about 50 percent goes for fertilizer production, while for irrigated grain 50 percent goes for irrigation and 25 percent for fertilizers. DVOSKIN et al. as referred by PATTON and LACEWELL /2/ estimated that the energy used for production of irrigated crops is from half to three times more than is required for comparable dry land production and about 25 percent of all direct energy used in crop and live-stock production is spent for irrigation. DVOSKIN et al. evaluated also the effect of high energy prices on irrigated agriculture for the United States. These economists showed that by doubling energy costs there would be an estimated reduction in irrigated land used of 12 percent, reduction in water used of 22 percent and reduction in natural gas used of 15 percent. They further stated that relative productivity of energy in irrigated region is smaller than in dry land regions, which means with high energy prices production would tend to shift from the irrigated regions to the dry land regions. With high

energy prices they estimated a reduction in irrigated acreage and nitrogen uses resulting in a smaller agricultural output. Energy costs are expected to continue increasing and in some areas, limited energy supplies may restrict irrigation development. Energy is a more complicating factor to be reckoned with by irrigator in making present and long range plans and decisions stated by HUMPHERYS/3/. According to ALVANI and CHANCELLOR /4/ non-irrigated wheat production appeared to offer higher output/input energy ratio i.e. 2,9 than did irrigated production which was only 1,9. However the lower yields of non irrigated wheat indicated that the inputs of land and solar energy per unit of output product energy were greater than for irrigated wheat.

JOHNSON /5/ stated that irrigation energy component can easily be 10 times the energy required of all other farm production activities combined. Energy related inputs can comprise 30 % of the total cost of producing one ton of irrigated corn which is nearly twice the level associated with dryland production.

KNUTSON et al. /7/ estimated that the electrical energy required to California's crop is 12 percent of total energy required by Californian agriculture. The investigators reported that 91 per cent of the application energy is used to pressurize sprinkler system even though only 17 per cent of the California's irrigated acreage is sprinkle irrigated.

WILLIAMS and CHANCELLOR /8/ in their mathematical model of crop yields as a function of five energy related inputs /fuel energy for production activities, tillage, fertilizer use, harvesting and irrigation water/ concluded that irrigation water reductions must certainly had the greatest effect upon the production value compared with the other inputs. They estimated that if the total irrigation water application were reduced to 75 percent of the optimum level, the total crop value will be reduced by 398 billion \$. While cutting the irrigation water application in half, it would reduce the crop value by 1122 billion \$.

TWERSKY and FISCHBACH /9/ reported that the total energy costs in crop budgets usually make up over 50 % of all variable costs, while irrigation energy cost almost always exceeds 25% of variable costs. They forecasted that cost of fuel and electrical energy, water supply, legislation, equipment, crop prices and weather will basically influence the future trends in energy uses.

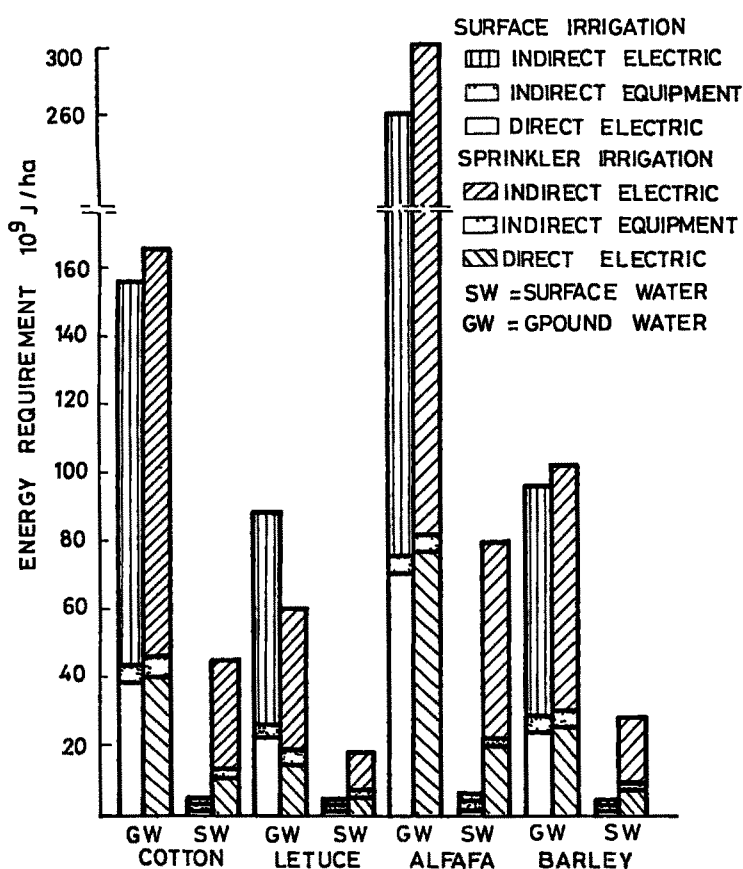


Fig. 2.1

LARSEN and FANGMEIR /11/ investigated the total energy requirement for all energy inputs /i.e. fertilizers, seeds, fuels etc./ of cotton, lettuce, alfalfa and barley production, and found that irrigation required a major part of the total energy, where deep wells were used /Fig.21 /. The investigator concluded that irrigation energy conservation holds the greatest promise for reducing total energy requirement of irrigated crop production.

TÓTH /12/ and KNUTSON et al. /7/ stated that modern irrigation is a complex task and the

decision of adopting a given irrigation system only partly depends upon energy requirement. Each system should suit to local conditions. Equally important factors in addition to energy are: soil type, irrigated area, crops to be irrigated, topography, weather conditions, availability and quality of water, cultivation practices, cropping pattern, energy required to bring the water to the field, sources of power, availability of labour, materials, machinery and other energy sources, possibility of obtaining necessary irrigation equipments, management capacity, marketing conditions for surplus produce and different special



irrigation requirements. That means the energy demand and cost for irrigation purposes are really very important factors of irrigated land production but they are not the only and even not the most important ones when economic decision should be made about the choosing of a given irrigation system.

2.2 Total energy inputs to irrigation

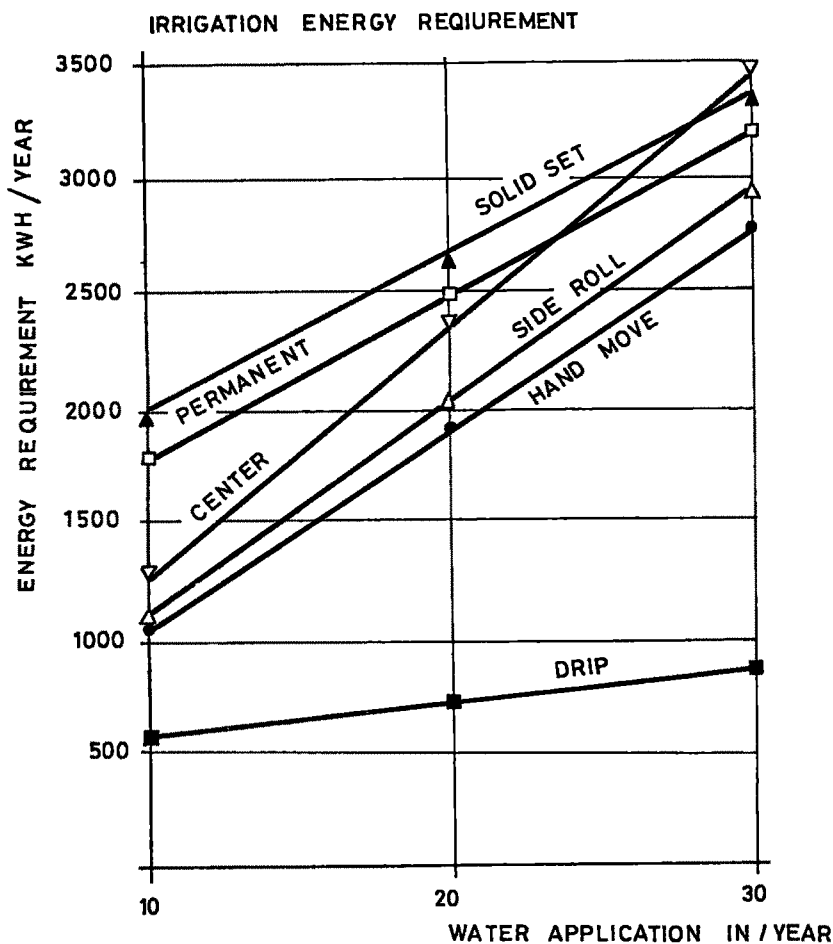
BATTY et al. /19/ have categorized the total energy inputs for any given irrigation system into two categories:

- installation energy demand and
- operation energy demand.

The installation of an irrigation system requires excavation, piping, fittings, delivery system, structures, pumping units and human labor for installation. They have computed also the energy for producing of plastic, aluminium, steel or brass involved in piping and fitting required and pumping units, electric motors and diesel engines. The accounting of human labour energy input was made with the assumption that man power expends approximately 12600 kJ /3000 kcal/ during a 10 hours working day.

The energy associated with irrigation system operation includes maintenance energy and pumping energy. The annual maintenance energy was calculated as 3 % of the installation energy for all systems except the solidset sprinkler system. They expressed pumping energy as mechanical energy whereas installation energies in forms of thermal units /kcal/. The investigators accounted for total annual energy inputs for nine irrigation systems designed for an actual 64 hectar farm, based on 915 mm net irrigation requirement and zero pumping lift. The results of this particular study indicated that the installation energy requirements are not negligible compared to the pumping energy demands /Appendix 2.1/. Ratio of installation energy to pumping energy vary from as high as 3,75 for surface irrigation to as low as 0,18 for traveller sprinkler.

CHEN et al. /20/ in their energy simulation model, considered the energy needs of each of the selected irrigation system into four basic areas: installation, operation, transportation and manufacturing. They examined seven different



ways of irrigation taking into consideration three different irrigation intensities /0,1; 0,2; 0,3 in/day/ i.e. 2,5; 5,0; 7,5 mm/day, three level of water application 10; 20 and 30 in/year and three different sizes of irrigated land /20; 80 and 160 acres i.e. 8; 32 and 64 ha/. From the various results of calculation on Fig.2.2 the seasonal energy requirements of different irrigation systems are shown.

Fig. 2.2

2.3 Energy demand of different irrigation systems

The operation energy requirement of irrigation depends basically upon two factors: the quantity of water required for irrigation processes and the technical solution as how the water is delivered onto the irrigated land. Therefore it is necessary to deal with these two factors separately, which are intricate from energy demand point of view.

2.3.1 Water requirement for irrigation

According to the relevant references - ZIMMERMAN /21/, PETRASOVITS and BALOGH /22/, BUDAVÁRI /23/ etc. the gross irrigation water requirement depends upon the following factors:

- existing climatic conditions, such as precipitation, evaporation, wind, temperature, sunshine duration etc.;
- soil characteristics, such as soil type, waterholding capacity of soil, moisture content and soil texture, salinity of soil and water, soil aeration requirement, topography, ground water situation, soil temperature etc.;
- crops and its variety, depth of root zone, cultivation practices, dry period etc.;
- irrigation method, i.e. sprinkler, flood, surface, subsurface, trickle irrigation etc.;
- irrigation equipments and their operation, daily operating period and frequencies;
- area to be irrigated and its configuration and leveling;
- degree of management and technical level of irrigation staff members.

ZIMMERMAN /21/ mentioned that the actual water requirement may vary considerably for the same crop inspite of uniform potential evaporation. Therefore consumptive utilization figures must be adjusted for every individual farm and land. PETRASOVITS and BALOGH /22/ stated the following equations for the irrigation water requirement of given crop:

$$V_{\text{össz}} = V_{\text{oi}} + V_v \quad [\text{m}^3]$$

where: $V_{\text{össz}}$ - total water requirement $/\text{m}^3/$; V_{oi} - irrigation water demand $/\text{m}^3/$; V_v - losses during irrigation $/\text{m}^3/$

and the irrigation water demand:

$$V_{oi} = \sum_1^n T - \sum_1^n [c - V_v] - W_1 \quad [m^3]$$

where: T - transpiration; c - precipitation; V_v - water losses; W_1 - moisture content of soil before irrigation; n - boundary limit values indicating starting and ending of irrigation period.

ERIE /24/ added that some water may be needed above and beyond the immediate plant requirements to aid germination, provide frost protection, control corn borers and caterpillars, dissolve fertilizers, loosen soils etc. and perhaps for other purposes. These needs although small must be considered under present concept of agricultural production.

The determination of irrigation water demand of different crops earlier was based on practical data. During last decade when the water shortage has become one of the most important national and international problem of the world more exact methods were developed. After PETRASOVITS /22/ and BUDAVÁRI /27/ the most important steps of calculation are, as follows:

- determination of cropping period /days/
- determination of potential evapotranspiration /ETP/
- determination of real evapotranspiration /ETR/

$$ETR = K \cdot ETP \quad [mm]$$

where: K - ratio of ETR and ETP, - taking up of expectable rainfall /mm/, - the rainfall efficiency factor /%/, - calculation of usefull rainfall /mm/, - determination of waterdemand balance, water stock in soil /mm/ and the critical and real irrigation water demand.

For practical use and only for orientation - among Hungarian average conditions - we might calculate with the irrigation water norms reported by SZILÁRD /25/ and GÁBORI /26/ presented in the Appendix 2.2. The nominal capacity of pumping plants related to 1 ha of irrigated land, according to calculation

prepared by BUDAVÁRI et al. /27/ are given also in Appendix 2.2.

2.3.2 Energy demand of different irrigation systems

Increasing energy costs and water shortage has aroused an interest in many irrigationist to compare relative energy requirement of different irrigation systems and to investigate an alternative irrigation systems demanding less energy and water.

LARSEN and FANGMEIER /11/ have estimated the irrigation energy requirement of selected crops, for both surface and ground water supplies using surface and sprinkler irrigation systems. With surface water supplies the surface irrigation required 13 - 38% and the sprinkler irrigation 44 - 88 % of total irrigation energy requirement. With ground water pumping, the total energy requirements were 2 - 17 times higher than surface water pumping. With the surface water source, sprinkler irrigation energy requirements were 5 - 12 times greater than surface irrigation, while with the ground water source, sprinkler irrigation energy requirements were only 6 - 7 times larger than surface irrigation.

TERRON /28/ has calculated on the average of $1,0 \text{ kWh/m}^3$ of specific energy consumption for sprinkler irrigation in some situations, while in case of trickle irrigation it was only about $0,15 \text{ kWh/m}^3$. PAZOS /29/ reported the figures of 400 kWh/ha as an average annual consumption of electricity in irrigation, while the sprinkler irrigation sharing the maximum i.e. 1400 kWh/ha .

PAPP /10/ reported the specific energy requirement for sprinkler irrigation as $0,3$ to $0,5 \text{ kWh/m}^3$ and for flood irrigation as $0,05$ to $0,15 \text{ kWh/m}^3$.

In case of diesel drive these energy requirement comes to 0,06 to 0,07 kg/m³ and 0,01 to 0,03 kg/m³ of diesel oil for sprinkler and flood irrigation, respectively. GAJÁRSZKY and GERENCSÉR /30/ reported the specific energy requirement for sprinkler and surface irrigation as 0,25 to 0,35 kWh/m³ and 0,02 to 0,03 kWh/m³ respectively. According to KERESZTURSZKY et al. /31/ for sprinkler irrigation on an average 50 to 60 HPh/100 m³ /36,7 to 44,1 kWh/100 m³/ energy is utilized.

LARSEN /32/ reported energy use values of electrified sprinkler and gravity irrigation systems in Idaho as shown in Appendix 2.3. CHEN et al. /20/ evaluated the total amount of non-renewable energy consumption of major irrigation systems by developing of energy-irrigation simulation model. The model output ranked the energy utilization hierarchy of the irrigation systems, as follows: surface, drip, sideroll handmove, center-pivot, permanent and solid-set system. They found that there was relatively small effect of field size on minimum energy requirement for each irrigation system, but indicated that solid-set and permanent designs should be based on small scale fields, hand move and side-roll designs reached minimum designs with 32 hectar fields and for drip and surface systems energy requirement remained relatively constant as the field sizes were varied from 8 to 64 hectars. They also found that increasing total seasonal water application from 254 mm to 762 mm on 64 hectar field increased the energy required ranging from 165 percent for a center pivot to zero percent for a surface system.

TWERSKY and FISCHBACH /9/ has given the comparative energy requirement for water application for low medium and high lift irrigation /Appendix 2.3/. From this comparison it is clear that irrigation systems with low lifts are the most energy conservative requiring the least application of energy. Center pivot systems with high water application rates and low pressure, use less energy than more conventional sprinkler system. They also showed that the energy demand of center pivot irrigation

increases at a faster rate with high lift than do other conventional sprinkler systems.

KNUTSON et al. /7/ in their study assumed that sprinkler would use 20 percent less water than surface irrigation methods, but requires additional energy per unit of water for pressurizing the system. The energy to pressurize a typical sprinkler system at $3,87 \text{ kp/cm}^2$ is $1770,5 \text{ kWh/ha}$, if the overall pumping plant efficiency is 59 percent. This is more than offset by the 20 percent saving in water. The investigators mentioned that sprinkler can also reduce total energy in case of extremely high suction lifts. They concluded that there is no ideal irrigation system consuming the least amount of energy.

SZÁSZ /12/ has ranked the energy requirement ascending order of irrigation as: surface, trickle, subsurface, portable and semi-permanent sprinkler irrigation. He presented the energy transmission methods in various irrigation systems as are given in Appendix 2.4. and on Fig. 2.3.

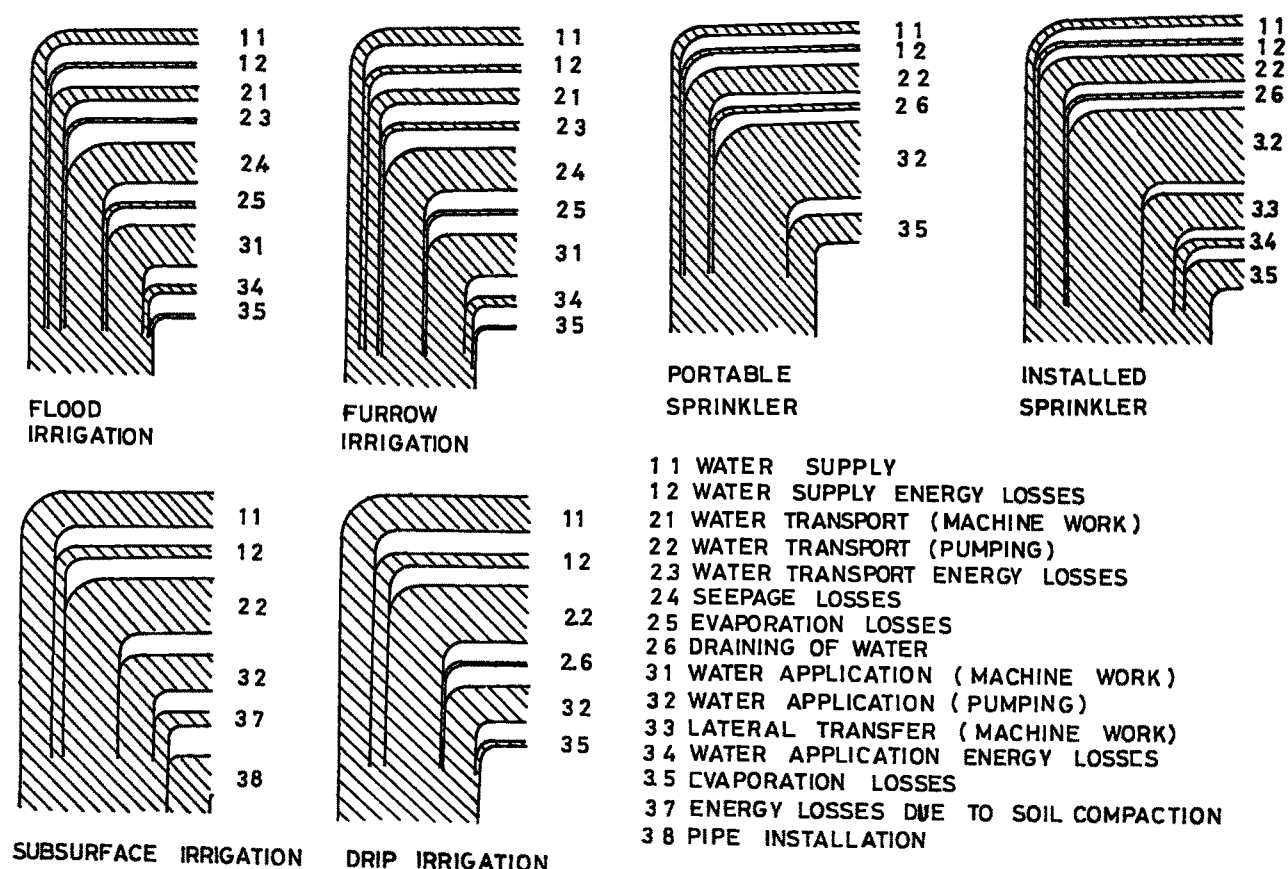


Fig. 2.3.

BATTY et al. /19/ stated that although surface irrigation appears to be far more energy conservative than either sprinkler or trickle irrigation, the large water saving offered by trickle and spirinkler irrigation may be more energy conservative than surface irrigation under special circumstances /Fig.2.4./. The total energy inputs per hectar of irrigated land, including installation and pumping energy demand, for examined nine irrigation systems /Appendix 2.1/ are illustrated on Fig.2.4, as a function of applied water lift.

2.3.3 Energy demand for pumping irrigation water

From the various references it is clear that the pumping of water is the most energy consuming operation in any irrigation system. ALVANI and CHANCELLOR /4/ concluded in general that non-irrigated wheat required less commercial energy per unit of production than did irrigated wheat. This difference appeared mainly in the form of electrical energy used for irrigation pumping. Studies in Nebraska as reported by GILLEY and WATTS /75/ have indicated over 40 % of all the energy consumed by production agriculture is used for pumping water from wells which supply about 80 % of the irrigation requirement. HALDERMAN /106/ stated that the irrigation pumping uses 5-20 times as much energy per hectar as all other power units used for crop production. SCHTEPA /37/ reported a yearly electric energy consumption for pumped irrigation as 1000... 3000 kWh/ha. The basic parameters affecting pumping energy demand are, the system pressure, the efficiency of pumping operation, and the water discharge of the pump. BATTY et al. /19/ proposed the following formula for estimating pumping energy:

$$PE = K \frac{A \cdot D \cdot H}{E_i \cdot E_p} \quad [\text{energy unit}]$$

where: PE - pumping energy /energy unit/; K - conversion factor depending on energy unit; A - area to be irrigated ; H - pumping head; E_i - irrigation efficiency; E_p - pumping efficiency; D - water application depth

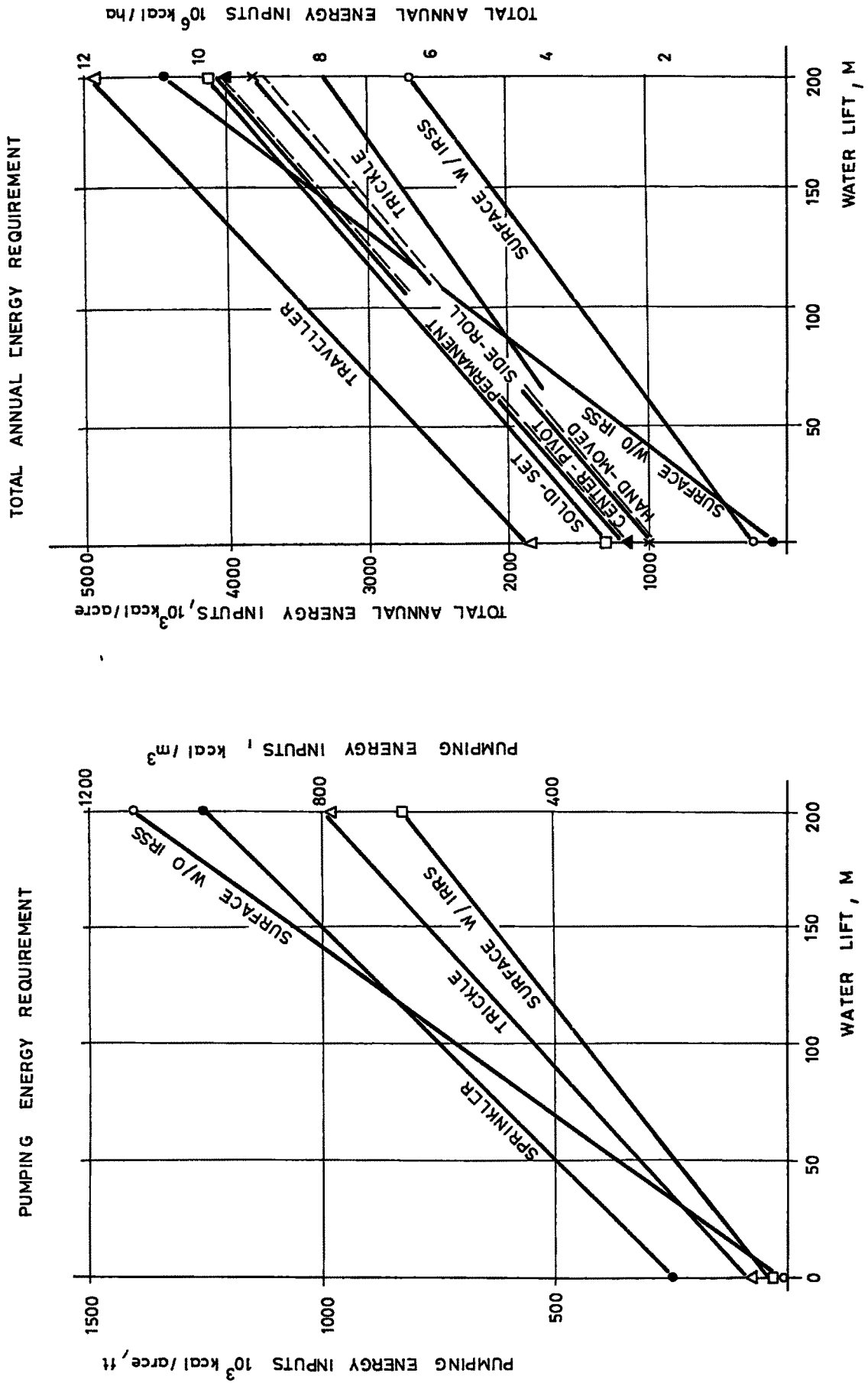


Fig. 2.4.

TÓTH et al. /12/ referred the following formula for calculation of pumping power requirement:

$$N = \frac{1000 \cdot Q \cdot H}{102 \cdot \eta_{sz}} \quad [\text{kW}]$$

where: N - pumping power demand /kW/; Q - water discharge /m³/s/; H - pumping head /m/; η_{sz} - pumping efficiency at given Q and H /%/.

The formula used by GILLEY and WATTS /75/:

$$PE = \frac{C \cdot A \cdot D \cdot H}{E} \quad [\text{Joule}]$$

where: PE - pumping energy demand /J/; C - conversion factor /9,81/; A - irrigated area /m²/; D - net depth of water applied /mm/; H - total dynamic head /m/; E - irrigation efficiency /%/.

According to TWERSKY and FISCHBACH /9/ energy to lift and supply water is consumed directly and indirectly. Water application is a direct energy requirement, where the energy requirement per unit of water volume and per unit of lift varies with both pumping plant size and overall pumping plant efficiency /OPE/. Electrical pumps showed lower energy requirements for average plant performance than diesel or natural gas. The investigators suggested that for electrical pumping plants energy consumption should be in the range of 0,0040-0,0053 kWh/m³/m, when the OPE is 50...60 percent. In California the energy to lift ground water is 0,0045 kWh/m³/m for an average lift of 41 meter.

MARJAI and PERÉNYI /38/ proposed the following equation for calculating the water requirement i.e. the total water discharge of irrigation pump, for a given cropped area at one schedule:

$$Q = \frac{W \cdot A}{3,6 \cdot N \cdot t} \quad [1/s]$$

where: W - yearly irrigation water demand /m³/ha/; A - area to be irrigated /ha/; N - number of irrigation days /days/; t - daily working period /hours/.

According to DOBOS /39/:

$$Q = 2,78 \frac{h \cdot A}{T \cdot t} \quad [l/s]$$

where: h - water norm for one irrigation schedule /mm/;
T - irrigation period /days/

The total dynamic head /H/ according to PAIR /40/ is determined by adding the calculated main line friction head loss, the calculated lateral friction losses plus the specified input values of sprinkler operating head, pump suction lift, friction losses in the suction line, elevation differences from pump to field and height of the riser pipe. In case of semipermanent sprinkler unit having subsurface installed pipe network ROSER /41/ determined the total dynamic head by following equation;

$$H = H_g + H_s + H_l + H_{sm} + H_m + H_p \quad [m]$$

where: H_g - geodetical elevation difference between the suction water level and sprinklers /m/; H_s - pressure required by sprinklers /m/; H_l - friction losses in lateral /m/; H_{sm} - friction losses in submain /m/; H_m - friction losses in main /m/; H_p - local friction losses due to pumps and common main /m/.

In practice, the first four components of the equation are generally constant for a given pumping unit. While the friction losses in main changes during the operation depending upon water discharge carried through them. Thus while determining pumping unit's H_{min} value these changes should be considered.

The typical Q-H curves for the semipermanent pumping unit are shown in Fig.2.5 The allowable head loss up to the critical point p of the pipe network is given, as follow:

$$H_a = H_m + H_{sm} + H_l = H_{man} - H_p - H_g - H_s \quad [m]$$

Where: H_a - the allowable pressure head loss /m/; H_{man} - the manometric discharge height of pumping unit /m/.

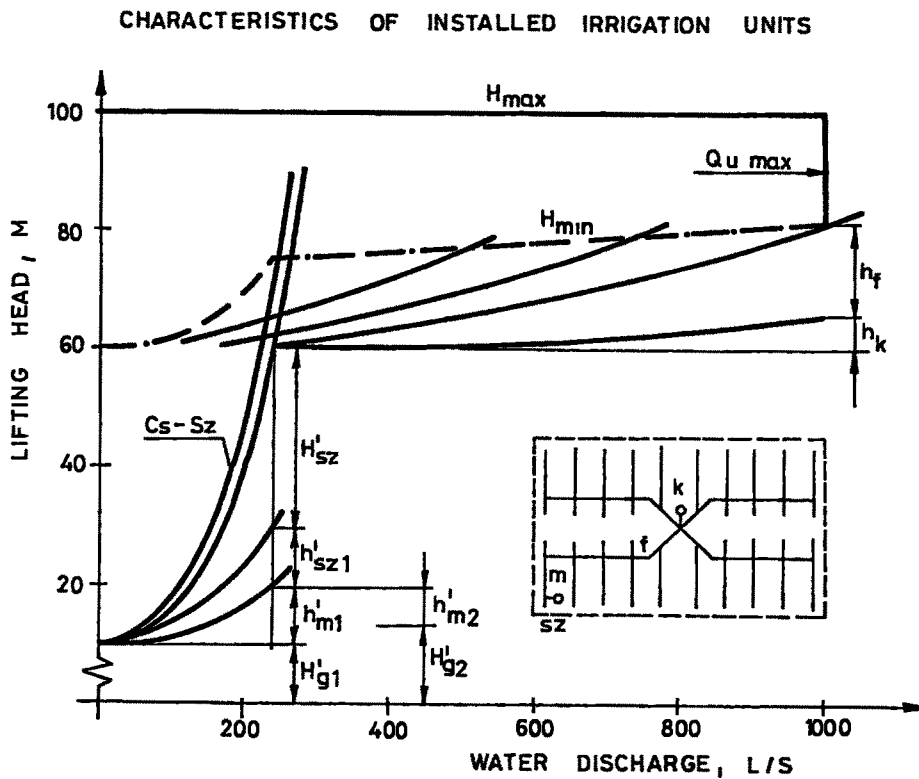
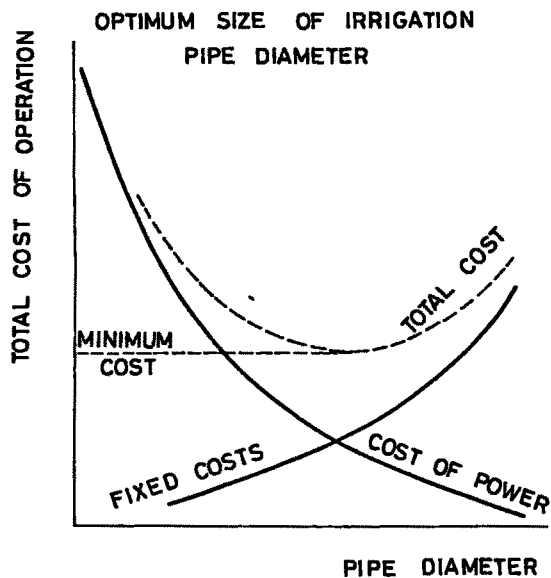


Fig. 2.5

2.4 Optimization of irrigation system parameters

The chief objective of optimization in irrigation is to secure a system that will provide a satisfactory water distribution over the field with a minimum annual operating cost, including depreciation, energy and labour costs. The optimization generally is carried out for economical selection of pipe or open canal dimensions, location of pumping station, route of the main conduit, suction lift and discharge head of the pumps, size and shape of area, and overall operating plan of the irrigated area.

Various procedures for selection of economical pipeline sizes for both simple unbranched pipeline, and branching network have been reported. The essence of economic mainline pipe size selection is to find the minimum sum of fixed costs plus operating costs on either a present worth or an annulized basis as shown in Fig.2.6 The optimum pipe size is where the sum of the fixed plus power costs is at a minimum.



VIZITERV have proposed the following empirical form of equation for calculating economical pipe diameter/ d_{opt} / of single series pipe lines without branches.

Fig.2.6

$$d_{opt} = 0,32 \sqrt[3]{Q_{av}} \sqrt[6]{\frac{e \cdot Q_y \cdot \lambda}{a \cdot b \cdot \eta}} \quad [m]$$

Where: Q_{av} - average discharge rate $/m^3/s/$; e - specific cost of energy $/Ft/kWh/$; λ - friction resistance factor for the pipe; Q_y - total volume of water per year $/m^3/$; a - annual depreciation factor; b - price factor for the pipe $/Ft/m^2/$; η - pumping efficiency $/\%/$.

IJJAS /49/, /50/, /51/ has developed an application programme package for large area sprinkler irrigation. He used linear and dynamic programming for dimensioning of branching irrigation network, determination of optimum route of the main conduit, optimum lift and discharge head and economical site of pumping station.

All the above mentioned approaches consider the cost of energy as constant over the systems life. But since the beginning of oil crisis there is an increase in the user cost of almost every form of energy. According to KELLER/45/ the cost of energy will double every eight year if the energy cost escalation tendency is expected to continue as present. The writer developed the chart approach to directly select the most economic pipe sizes for a given set of economic parameters, which includes present worth factor /PW/ and equivalent annualized factor /EAE/ of the escalating energy, and capital recovery factor /CRF/.

In order to assess the effect of escalating energy factor in economical pipe size selection KIZER et al. /52/ developed a model to compare optimum energy designs to minimum economic designs for farm irrigation main lines. The model determined minimum energy designs by considering both the energy needed to manufacture the pipe line and the energy required to operate specific systems. The minimum economic designs on the other hand, considered the retail price to purchase the system and the cost of electric power to pump water through selected designs. The model output showed that the energy minimum design does not become economically optimal in most cases until the price of electricity increases considerably compared to present levels. Another similar attempt by CHEN et al. /53/ lead to the conclusion that the difference in annual fossil energy requirement and economic cost between energy and economic design were relatively small. However, initial investment costs of the energy designs averaged 11,6 % larger than the economic designs, while economic designs annually consumed an average of 76 kWh more electric energy than energy designs.

FEKETE /54/, /55/ carried out several examinations regarding optimum number of sprinklers per lateral and their intensity, number of simultaneously operating laterals per submain, optimal size and shape of area, location of pumping station and pump discharge head which will result in most economical cost of installed pipe network.

2.5 Energy losses in irrigation systems

Energy losses in irrigation may be categorized as direct and indirect. Hydraulic losses due to friction in pipes, and excess fuel or electricity consumption due to poor pumping efficiency etc. are direct energy losses. Indirect losses originate from water losses occurring during irrigation process, and wastage of energy inputs like fertilizer due to deep percolation. Here I deal only with direct energy losses.

Water flowing through pipeline is accompanied by two types of energy losses: friction losses and minor losses. Loss of pressure takes place due to friction. There are several well known formulae given by designers such as: Weisbach, Scobey, Hazen-William, Colebrook-White, Christiansen, etc. For practical purposes following formulae given in SI units are most common. The Hazen-Williams equation as used by IJJAS /49/ and BUDAVÁRI /23/ is stated as follows:

$$\epsilon = \alpha \cdot 0,21 \cdot Q^{1,85} \cdot D^{-4,86} \quad [\text{m}/100 \text{ m}]$$

The modified form of above equation is:

$$\epsilon = \alpha \left[\frac{v}{354,57 \cdot D^{0,63}} \right]^{1,85} \quad [\text{m}/100 \text{ m}]$$

where: ϵ - specific pressure head loss /m/100 m/;
 α - material and pipe coefficient; Q - water-flow /m³/s/; D - pipe diameter /m/;
 v - velocity of water /m/s/.

FEKETE and DOBOS /55/ estimated friction head loss using the following DARCY-WEISBACH formula:

$$h_v = \frac{v^2}{2g} \cdot \lambda \cdot \frac{l}{D} \quad [\text{m}]$$

where: h_v - pressure loss in pipe /m/; λ - friction factor; l - length of pipe /m/; v - water velocity /m/s/; D - diameter of pipe /m/.

The above formula further converted by DOBOS /55/ to:

$$h_v = B \cdot Q^2 \cdot l \quad [m]$$

where: B - pipe-line characteristics / $25 \cdot 10^{-5}$ to $90 \cdot 10^{-5}$ /;
Q - water discharge / m^3/s /

DOBOS /55/ developed the following form of equation for determination of pressure head loss in sprinkler laterals:

$$h_{sz} = BQ_1^2 l \left[C_1 + kC_2 + kC_3 + \frac{(n + kC_5)^2}{2} \right] \quad [m]$$

$$h_{sz} = C_4 \cdot Q_1^2 \quad [m]$$

where: h_{sz} - pressure head loss in lateral /m/; B - lateral pipe characteristics / $40 \cdot 10^{-5}$ to $90 \cdot 10^{-5}$ /;
 Q_1 - water discharge of the farthest sprinkler / l/s /;
 l - sprinkler spacing on lateral /m/; k - factor depends upon cross section area of the nozzle;
 C_1, C_2, C_3, C_4, C_5 - dimensionless factors depending on the number of sprinklers per lateral and for the given nozzle size.

Some additional energy losses take place as the water passes through various types of fittings and changes in sections such as couplers, bends, valves, contractions and expansions in cross section wall-wall angles, entrance and exit sections. For expressing head loss through fittings and changes in sections, equivalent length method is used when the conventional friction loss formulae are used. However modern practice is to express losses through fittings in terms of the velocity head stated as follow:

$$h_f = \frac{k \cdot v^2}{2g} \quad [m]$$

where: k - the loss coefficient, depending on the type of fitting and section; v - velocity of water / m/s /.

FEKETE and DOBOS /55/ used the following equation for estimating friction loss in various types of fittings:

$$h_f = C \cdot Q^2 \quad [m]$$

where: C - fitting's characteristic; Q - water discharge through pipe /m³/s/.

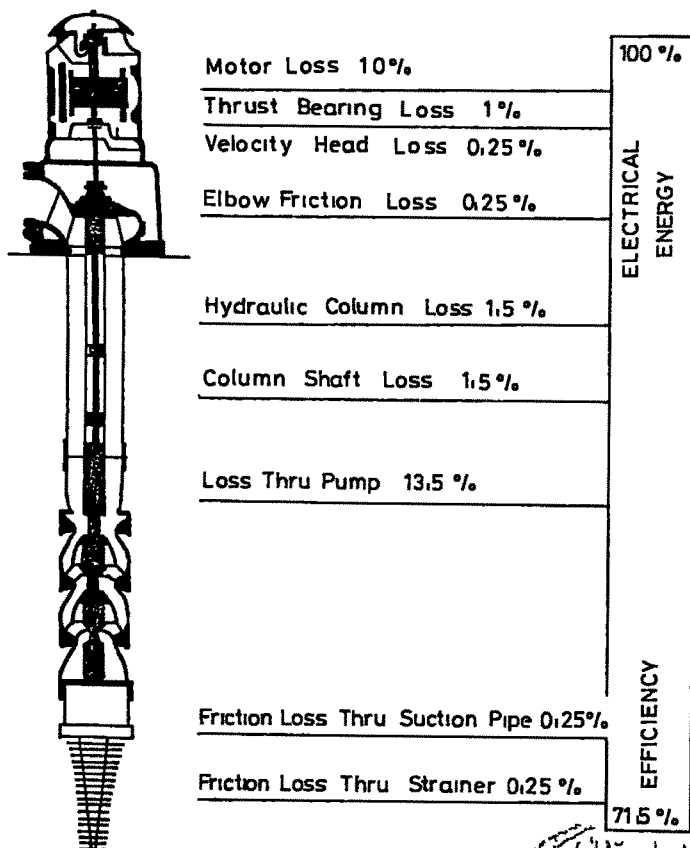


Fig.2.7.

The efficiency of larger irrigation pumps i.e. above 100 kW capacity are designed to run at about 68... 70 % efficiency while design efficiencies for smaller pumps are slightly lower i.e. 60...64 %. The various kinds of friction losses i.e. friction losses in the motor, bearing, drive column, and pump itself are shown in Fig.2.7.

FISCHBACH-SULEK /61/ outlined various causes of poor pumping plant performance originating from pump, engine and

drive; improper adjustment of pump impellers, not matching of impellers due to changing pumping conditions, operation of pump below or above the design speed, under or over loading of engine, loss of compression due to leaky valves, not matching of engine to the fuel used, incorrect drive ratio for matching pump and engine speed, drive misalignment etc.

A study of the diesel engine pumpset installations carried out in India /62/ indicated that the overall efficiency varied between 23...37 % even compared to 50 % normally assu-

med, which gave 159...200 % higher diesel oil consumption than the optimum. The major factors responsible for lower efficiency as put forth by the writer are: improper selection of pumpset not matching with the hydro-geological characteristics, well performances and other technical requirements; improper designing of the irrigation system, under size suction and delivery pipes causing high friction losses, use of foot valves having low quality and poor specifications, low quality diesel engines, larger capacity of them were either under loaded or over loaded, and inadequate care and maintenance.

STROH /63/, /64/ pointed out several types of energy leaks in routine irrigation operation such as: leaking valves and gaskets, cracked pipelines, missing drain plugs, leaking sprinkler heads, worn nozzles; low efficient pumps caused by worn impeller seals, improper impeller adjustment, pumping of sand, poor design and pump selection, poor maintenance and operating conditions can waste great deal of energy. Many times the main valve is throttled for pressure regulation when only part of the laterals on the system are in operation. The investigators observed that when the main valve on the discharge pipe was partially closed, efficiency was cutoff in half and energy consumption was increased to 63 % compared to full capacity operation of the pump.

2.6 Possible ways of saving irrigation energy and energy cost

Increasing energy prices and energy shortages have conceived an interest in many irrigationists, to find out various ways and means for reducing energy and energy cost of irrigation. Some of these investigators have developed direct energy saving methods while others have suggested various procedures to reduce irrigation water or other input energy requirements, thus directly saving the overall energy demands.

Following are the various possibilities proposed by them:

- reducing the amount of water to be pumped,
- lowering the pressure requirements,
- improving overall pumping efficiency,
- adopting automatic control devices,
- decreasing peak electrical demands,
- improved management and education of staff,
- using alternative sources of energy.

Since energy consumption is directly and linearly dependent on water quantities, any reduction in water to be pumped will yield a corresponding reduction in energy consumption even if no other changes are made in the irrigation system or pumping plant. The Fig. 2.8 presented by HEERMANN /73/ illustrates the energy conserved as a function of water conserved and lift in an irrigation well. For only 25,4 mm saving of irrigation water 58,0 kWh/ha could be saved for a lift of 30,5 meter. The ways to reduce the amount of water pumped as proposed by various research workers are:

- improving irrigation efficiency,
- scheduling of irrigation,
- reduction of irrigation water losses,
- installing automatic control devices and
- installing tail water reuse system.

HAGAN et al. /65/ mentioned that the potential farm irrigation efficiency is in the range of 85 to 90 percent. Thus by raising the present average farm irrigation efficiency from 47 to 65 percent considerable amount of water and energy will be saved. In a well designed sprinkler irrigation system the maximum water application efficiency attainable according to HEERMANN /73/ may be as high as 90 percent. GILLEY and WATTS /75/, TWERSKY and FISCHBACH /9/ and CHEN et al. /53/ reported the irrigation efficiency values for selected irrigation systems, given in Table 2.1.

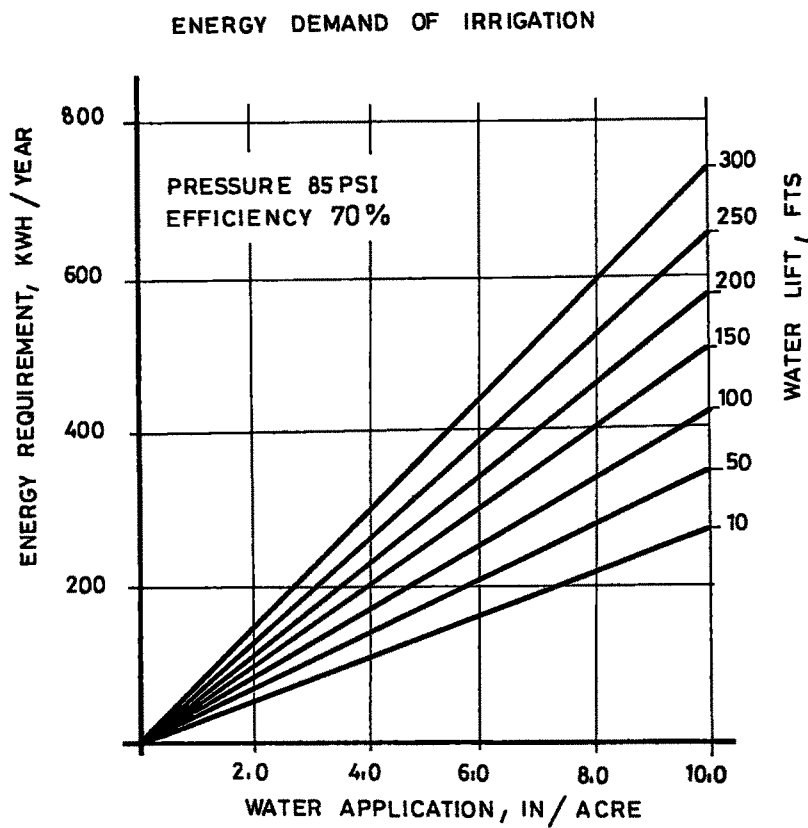


Fig.2.8

Irrigation efficiency values for selected systems

Table 2.1

Irrigation	Irrigation efficiency %	
	range	average
Surface	30-70	60
Surface with run off use	85 or higher	65
Auto surface with run-off use	75-90	80
Sprinkler	60-90	75
Trickle	75-95	90

They are of the opinion that the new irrigation techniques such as trickle, have potential to increase efficiency and reduce water application but because of high initial cost may not be feasible in production of field crops such as grain and corn. However as energy cost increases these type of systems may become more acceptable. SECKLER et al. /76/ stated that an automated sprinkler system can attain farm irrigation efficiency of about 85 percent while conventional furrow irrigation efficiencies are usually within the range of 45 to 65 percent depending on capital and management inputs.

WILLARDSON /77/ has listed the physical, economical and political factors controlling irrigation efficiency. Physical factors affecting water application efficiency for surface irrigation are the slope and roughness of soil surfaces, the soil infiltration characteristics, the stream size and the volume of soil available for water storage. For sprinkler irrigation, sprinkler spacing, nozzle size and pressure are important factors. Trickle irrigation efficiency depends on the spacing of the emitters and the rate of water application relative to the evapotranspiration rate. Economical factors that may directly or indirectly affect water application efficiency are water costs and their relation to land preparation costs and labour costs, equipment costs and the value of crop being irrigated. He emphasized that uniformity of water application is the key to high water application efficiency in any kind of irrigation. KRUSE and HEERMANN /71/ stated that farm irrigation efficiencies vary greatly depending on water supply, type of irrigation system, crop, soil and especially the level of management provided by irrigator.

HUMPHERYS /78/ designed an automatic cut-back furrow irrigation system, with which irrigation efficiencies of 75 to 80 percent can be obtained. In addition to saving of water and fertilizer requirement, the system reduced also the labour demand by 90 percent. Studies conducted by FISCHBACH /79/, /80/ with automatic surface irrigation system using gated pipe and a reuse system indicated that the irrigation efficiency as high as 92 percent could be achieved.

WORSTELL /34/ designed an automatic buried, lateral multi-set gravity irrigation system, which as reported by him reduced energy and labour requirement and increased water application efficiency of 90 to 95 percent.

By the help of precision scheduling of irrigation as stated by PAIR /81/ limited water supply can be realized along with optimum amounts of water at optimum time intervals, when water supplies are unlimited, to maximize the economic returns. HEERMANN /73/ described irrigation scheduling as the procedure which not only monitors either soil or plant water status but also forecasts an optimum time for future irrigations involving application of right amount of water at right time. Irrigation scheduling technique have been proposed by many scientists /82/, /83/, /85/, /86/, etc. as the main source of reducing the net amount of water pumped.

Studies by WATTS et al. as referred by GILLEY and WATTS /75/ have shown that irrigation scheduling procedure could save between 15 to 35 per cent of the water presently being pumped. An average of 20 and 35 percent saving of water pumped was possible to realize for center-pivot sprinkler and runoff reuse surface irrigation system, respectively. HILLER et al. /83/ indicated that advanced scheduling methods involving plant pressure and stress day index may further reduce the average annual irrigation requirement of the crops without reduction in crop yields.

Scheduling irrigation through programmed soil moisture depletion as developed by FISCHBACH and SOMERHALDERS /87/ and referred by FISCHBACH /85/ makes effective use of the rainfall during the growing season by partial filling of the root zone in each irrigation, thus allowing room for potential rain fall. By using the USDA irrigation scheduling technique HEERMANN /74/ found that 25...50 mm less water was applied with an estimated saving of 12...50 dollars/ha.

Reduction of water losses consists of reducing seepage, evaporation, deep percolation and surface run off during conveyance and distribution and, field application of irrigation water. HAGAN et al. /65/ suggested that in surface irrigation improved water distribution over a field can be achieved by land smoothing and grading, using suitable stream size and application of automatic controls. While the evapotranspiration from plants and land surface along the canal could be minimized by lining natural water ways and controlling pherotophytes. To reduce deep perlocation losses SALOUEV and ANDONOV /89/ proposed that shallow root plants should be irrigated more frequently with small application rate while deep root crops watering is to be rare and with a greater application rate.

PRICOP et al. /90/ presented an operational programme for optimization of pumping and repumping station in irrigation systems, to get better correlation between the consumers water requirements and the flows into the canals. Thus minimizing evacuation losses due to unused water and also water deficits. PALACIOS /91/ showed in a Mexican irrigation district that the conveyance efficiency of canals was increased more than 8 % by changing the operation rules, reducing the changes in water releases, and by improving the training of personnel working in water management. GULATI and MURTY /92/ observed that the pattern of water releases in India is not in accordance with the evapotranspiration requirements of the cropping pattern, and better return could be obtained by suitably modifying the canal water releases.

PERI and KARMELI /93/ recommended the application of new technologies such as volumetric valves, regulated emitters and hydropulse emitters which may lead to saving of water and energy in a wide range depending on the operating conditions of the irrigation systems. The writers estimated it to be in the range of 2... 17 %, 4... 37 %, 7... 53 % and 10... 75 % for favorable, moderate, poor, and extremely poor operating conditions respectively. HAGAN et al. /65/ stated that an efficient use of irrigation water in surface irrigation system

often results in some runoff or tail water which can be utilized by collecting and reusing it, thus reducing water delivery requirement to field. GILLEY and WATTS /75/ reported that the installation of runoff reuse system can provide significant energy saving in surface irrigation. An additional energy which is required to power the reuse system is smaller compared to the energy required to pump the water from original source.

PAIR et al. /81/ suggested that in areas where the irrigation season is long and power costs are relatively high consideration may be given to reducing the pressure losses in laterals well below the allowable pressure variation in order to reduce overall pumping cost for the season.

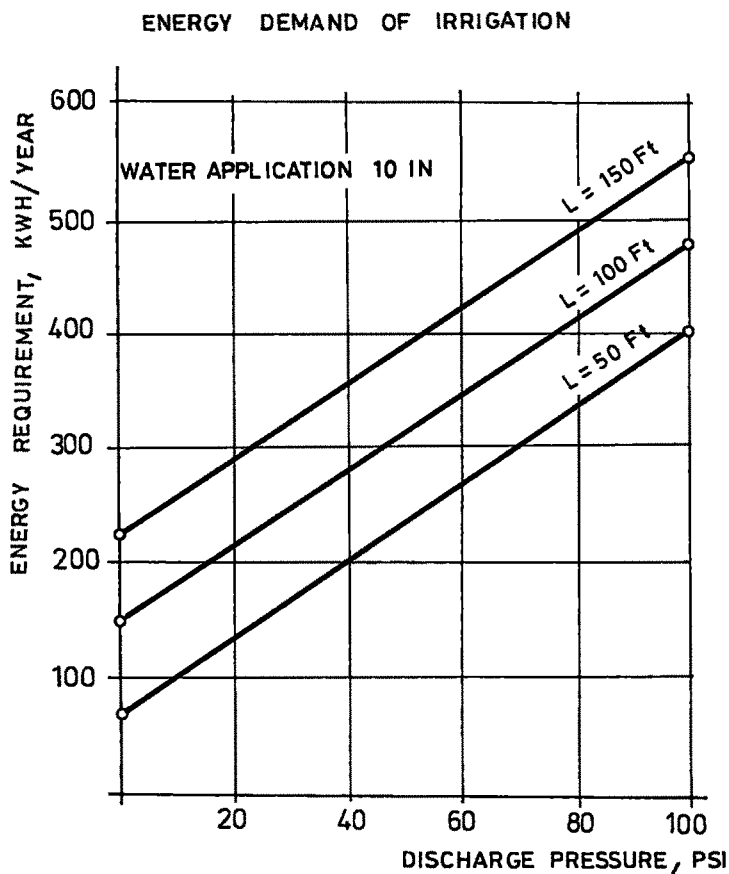


Fig. 2.9

HEERMANN /73/ explained graphically /Fig. 2.9/, how the energy required to pump water increases as the pressure increases. An average irrigation requirement of 457 mm with a lift of 30 m would use 75.000 kWh and 33.000 kWh at discharge pressure of 60 and 21 m respectively.

Operating the irrigation system at low pressure thus at lower pumping head, the potential energy saving can be achieved

as mentioned by GILLEY and WATTS /75/. However they pointed out that the pressure reduction necessary to achieve relatively large energy savings may not be practical due to optimum pressure requirement which is necessary for uniform water application, non erosive droplet sizes and to drive the

sprinkler heads. They suggested the use of small booster pump to supply water at high pressure directly to the gun of center-pivot system, which requires higher pressure than the smaller sprinklers on the main line, thus reducing additional pressure in the main line.

BRENDA /67/ suggested the application of a multistage irrigation water transport in designing large area irrigation schemes. The writer showed that by adopting two and four pumping stations instead of a single over 2000 hectares of land, an electric energy saving of 10 % and 15 % respectively would be achieved as compared to single pumping station. The manometric delivery head H_{lim} which will decide the border line between single stage and multistage pumping was given as:

$$H_{lim} = 90,2 + 0,86 h_g \quad [m]$$

where: h_g - geodetic delivery head /m/.

BIKI /105/ found that by operating the gated hoses with low pressure, specific yearly cost of operating equipment ranged between 0,68... 1,53 Ft/m³, while that of high pressure between 1,11... 2,98 Ft/m³.

PAIR et al. /81/ stated that the amount of annual power costs will depend on the type of power unit used, cost of fuel or energy and the overall efficiency of the pumping plant. Data taken by NOFFKE et al. and referred by GILLEY and WATTS /75/ on natural gas and propane power units indicated that an improvement in the performance rating by pumping plant adjustment from 0,66 to 0,76 is possible and this improvement alone would provide a 13 percent reduction in energy required. They further suggested that it is possible to raise the performance rating of the pumping plant from their present values to values close to 1,0 by replacing the less efficient older pumping plants with new ones meeting the Nebraska Standards. These potential energy saving range from 20 percent for electrical power units to 39 percent for natural gas units.

LARSEN / 32 / stated that an electrical powered pumping system should have an efficiency of 65... 70 % and found that when the efficiency was raised from 52 to 60 % the energy saving was 13 %. CHANDORKAR /62/ suggested that in order to increase pumping unit efficiency strict quality control in manufacturing of pumping units and selection of suitable match of engine and pump is highly essential. According to Halderman /106/, although some mechanical, thermal, electrical and hydraulic losses are unavoidable, should not become excessive, and which can be accomplished through regular performance checks, maintenance and repairs at suitable intervals.

GAJÁRSZKY and GERENCSEÉ / 30 / in their investigations for determination of the suitable combination of pumping sets for reducing power consumption, examined the two types of pumping combinations, namely a plant equipped with pumps of identical capacity and one with half capacity. They found that pumping station equipped with three major and two half-capacity pumps have displayed optimum performance characteristics. Where a pumping plant consists more than one pump, it is generally more economical to operate the minimum number of pumps that will furnish the required discharge. Thus it is less costly to run one pump at full capacity rather than two pumps at half capacity.

GAJÁRSZKY and GERENCSEÉ / 30 / noted that the automatic control devices installed at the pumping stations have resulted in more economical operation. About 34 percent of energy saving was observed by operating the unit with automatic control devices which regulated the pressure in accordance with the point of irrigation within the section.

RÓSER /110/ stated that narrowing the operating pressure range of the pumping unit by adopting automatic controls, considerable energy saving can be achieved due to elimination of extra pressure demand. Out of many possible solutions proposed by the writer, the objective and reliable ones are:

- repeated intermediate operation of basic pumps when same size of pumps are installed;
- selecting the pumps of flat and stable characteristics curves,
- regulation of pump speed using thyristor drive regulators, according to the pressure in the network /Fig.2.10./

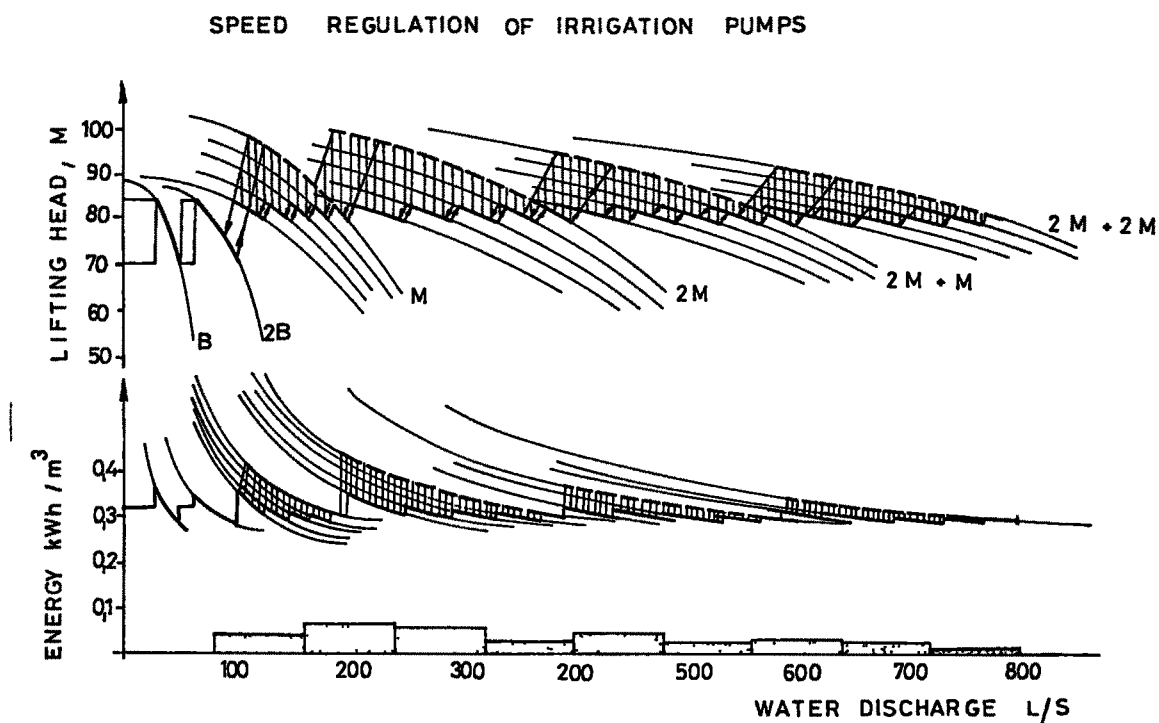


Fig.2.10

It was shown that about 0,25 MPa excess pressure can be saved by speed regulator when pumps were partially loaded and all the mains carried uniform water discharge. GERENCSEK /111/ concluded that the thyristor type revolution regulators can be applied for changing rotation of pumps and results in significant saving of electric power in the case of oscillating water level viz. suction head. STROH et al. /63/ in the test of diesel pumpset found that speed variation didnot appreciably vary the efficiency but it varied the pressure and the fuel consumption rate considerably.

The cost of electricity is determined not only by the total energy use, but also by the minimum rate of power consumption or the peak demand. Effects of off-peak irrigation experiments to reduce peak power demand have been reported by /85/, /112/, /113/, /114/ etc. During peak hours the power to the irrigation could be cut off by radio control devices, time clock or temperature controllers, telemetering systems, ripple control system or by manual switching. FISCHBACH /85/ reported that by scheduling electric motor driven wells out of peak hours, the total peak hours power demand of irrigation could be decreased from 19 MW to 15 MW. Another method suggested by him is to group the pumping plants in set of three units. One of the three systems would be shut off when the others were operating. An experiment conducted by STETSON et al. /112/ to schedule operation of irrigation systems electric demand showed that peak summer demand loads can be considerably reduced.

The operating expenses are also affected by the extent of utilization of the irrigation equipments. In one study of VIZITERV and referred by BUDAVÁRI et al. /23/ found that instead of planned water demand of 200 mm per year, if for example only 100 mm is applied, then irrigation expenses increase by 150 % /Fig.2.11/ thus by maximum utilization of installed capacity, lower specific operation cost can be achieved.

KELLY /115/ stated that due to the supply problems and sharp price increase of the conventional power sources, the alternative energy source for irrigation pumping may be a fuel involving already developed technology, such as coal, wind or it may be an energy source from an emerging technology such as solar and biogas energy. However its possible application will depend on its reliable availability, susceptibility to control by farmers, and cost low enough to permit farmers a reasonable return on their investments and efforts. There are few other references /116/, /117/, /118/ etc. reporting successful application of solar energy for irrigation pumping.

TWERSKY and FISCHBACH / 9/ found that auto-surface, gated pipe systems with water reuse, and trickle system had the most compatible low energy requirements to apply water with photovoltaic solar arrays and the pumping energy required ranged from 0,12... 0,17 kWh/m³ from a low-lift /15 m/ system. In New Mexico, solar powered pumping unit irrigating 53 hectars area is in operation. The water is pumped up from 33 meter deep well into a reservoir from where it flows to the low pressure system. It was reported that the unit could save an yearly energy equivalent of 8500 m³ of natural gas. In another system using array of solar cells generated 25 kW of power and pumped 60 l/s of water into irrigation system covering 32 hectars.

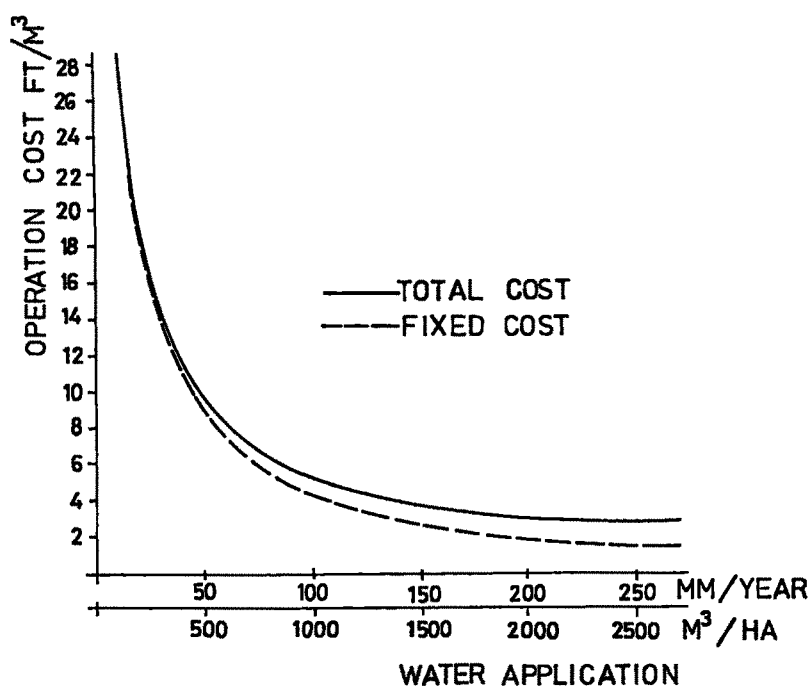


Fig. 2.11

2.7 Critical evaluation of the refered literature

The literature reviewed in the previous part of the dissertation has encompassed various efforts by several investigators, concerning implication of energy in irrigation, total energy inputs to irrigation, energy demand and losses of irrigation systems, and have suggested some possible ways of saving energy and energy cost. However, I feel that the scope of investigation of energy aspects in irrigation process is much wider and needs further lines of extension depending on local situations. Following are some important notices from the evaluated literature.

Many investigators have dealt with different irrigation systems operated on small scale, and I did not find any detailed energy investigations on large scale sprinkler system, especially of semi-permanent type, having sophisticated automatic control instrumentation. Since the semi-permanent sprinkler systems established in Hungary are the latest development in the field of irrigation engineering, their energy utilization characteristics should be examined for judging their competitiveness with other system of irrigation.

Although calculation of pumping energy demand and energy cost of irrigation can be determined by simple and well known formulae, there is no concrete procedure to determine total pumping energy i.e. starting from water source upto water application, and related energy cost. The computerized model No.1 provides the mean for using modification of 25 varying parameters, which were never used by any investigator.

There are well known and established procedures all over the world, for determining optimal diameter of irrigation pipe lines. Nevertheless, there are but few investigations dealing with new approach of optimizing pipe diameter i.e. on the basis of energy price escalation trend. The semi-permanent sprinkler

system involves considerable pipe-network, therefore it would be worth to develop modified procedure of optimum pipe size selection under hungarian circumstances using local values of energy prices. The details of procedure developed are presented in Model No.2.

There are some references concerning determination of optimal size and shape of irrigation field resulting in minimum pipe network investment cost. However, there is no investigation or procedure dealing with comparison of minimum investment design and minimum energy design for various irrigation unit sizes, involving investment cost of pumps, water and electricity supply, and pipe network. The Model No.3 is developed on the basis of preceding concept.

The aforementioned discussion point out the gap in the existing literature and suggests the necessity of carrying out further investigations in the field of irrigation energy economy. With this foundation I formulated my own and new lines of research activity described in detail in the succeeding chapters of this dissertation.

3. ENERGY DEMAND PATTERN OF LARGE AREA SEMI- PERMANENT SPRINKLER IRRIGATION SYSTEMS

According to the main objectives of my research programme, starting from conclusions of the evaluated literature in the second chapter of the thesis, I deal in this chapter with outlying the results of data collection and field experiments carried out to prepare a practical background for further theoretical analysis of irrigation energy relationships.

In this part of my dissertation after short introduction of the experiment site being the most up-to-date irrigation plant in Hungary and belonging to TISZA-II. project in SZOLNOK-MEZŐHÉK region, the overall energy consumption of the region and selected irrigation plants are demonstrated. After appreciation of overall many years' basic data for specific energy and energy cost parameters, I proceeded to evaluate the results of short-term field experiments which were organized specially for the purposes of this research programme. In this framework I carried out two main experiments at MEZŐHÉK-I pumping unit. First experiment deals with the determination of pumping unit efficiencies, while second deals with observation of characteristic interrelation between hydrant-pump operation. Both the experiments are important for analysing the energy demand pattern of the pumping units.

3.1 Introduction to the experiment site

The KISKORE irrigation project called TISZA-II, has created an irrigation potential of 300 thousand hectares in middle eastern part of Hungary /Fig. 3.1/. The project consists mainly of the NAGYKUNSÁG, JÁSZSÁG and BACKWATER irrigation sections. Water to the 126000 hectares of the NAGYKUNSÁG section is conveyed by the 80 m³/s capacity NAGYKUNSÁG main canal.

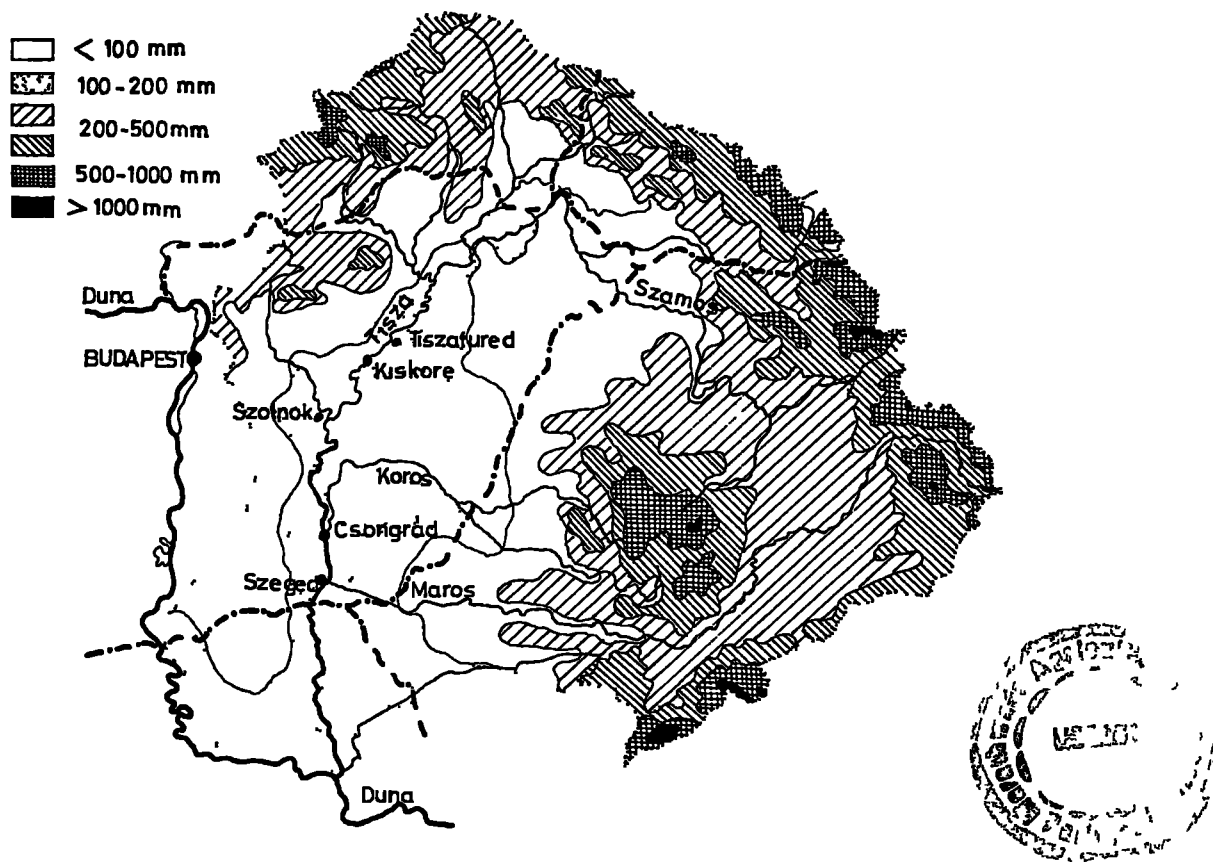


Fig.3.1 Rainfall distribution in Eastern part of Hungary

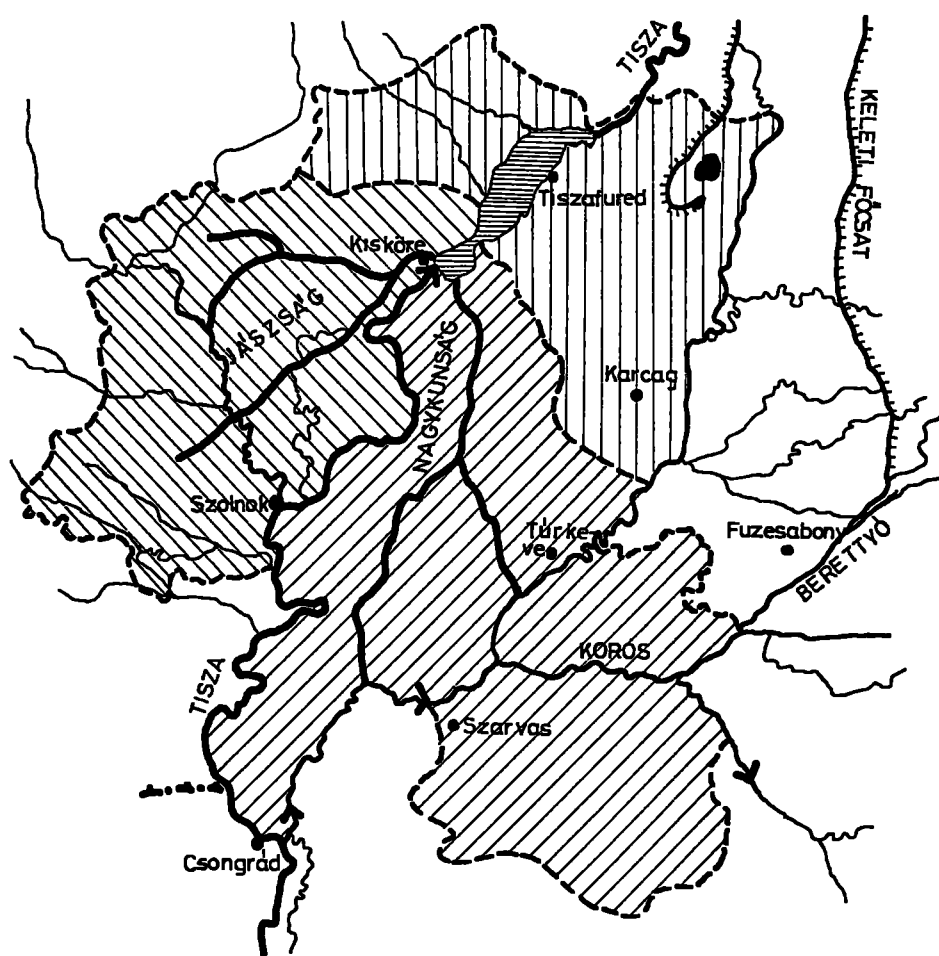


Fig.3.2 The overall view of TISZA-II. irrigation project

While to the 72000 hectares of the JÁSZSÁG section by the 48 m³/s capacity JÁSZSÁG main canal /Fig. 3.2/. The three main irrigation sections are further divided into 44 subsections.

Under the TISZA-II complex irrigation development programme a number of sprinkler irrigation schemes are contemplated in the various subsections of the KISKÖRE project. For the sake of carrying out detailed and extensive energetic study and related field experiments, the most up-to-date large scale semi-permanent sprinkler irrigation plants established under NAGYKUNSÁG-XII. subsection in MEZŐHÉK-TISZAFOLDVÁR district were selected.

The NAGYKUNSÁG-XII. subsection consists of six concentrated pressure pumping units of very high capacity, irrigating all together 7456 hectares of land /Fig. 3.3/. All the six units are equipped with sophisticated instrumentation, while four of them have automatic operation control facilities. As a result the establishment become highly capital intensive with the average specific cost of 30000 Ft/ha. The most important technical and economical data of the six units is given in Appendix 3.1.

3.1.1 Technical facilities of the irrigation units

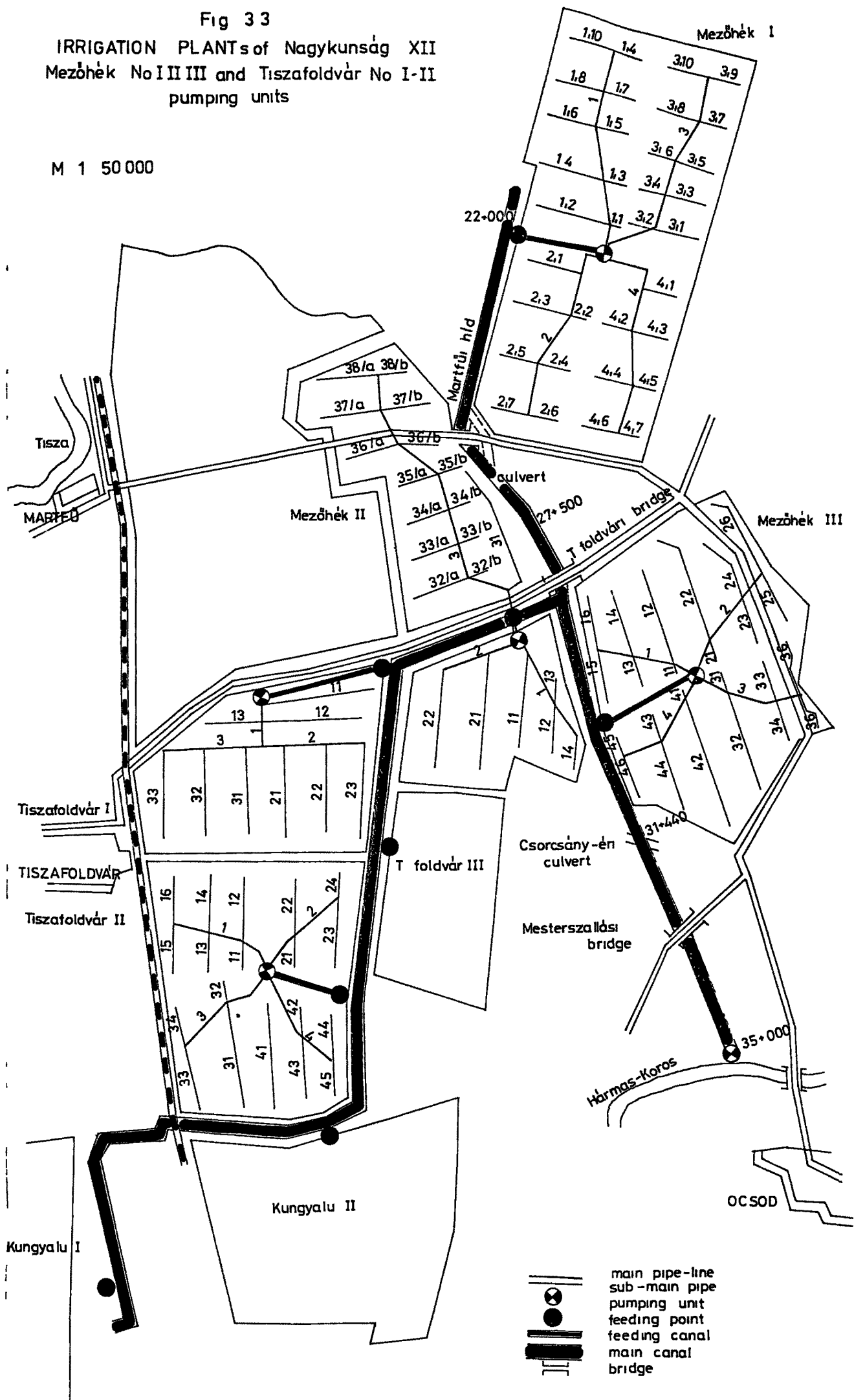
The technical facilities of the sprinkler irrigation units can broadly be grouped in following main components:

- water supply to the pumps,
- pressure pumping centre, consisting of pumps, power supply equipments, automatic control, air pressure tanks etc.,
- subsurface pipe network,
- surface sprinkler irrigation laterals.

Irrigation water from the NAGYKUNSÁG-2. Main canal is diverted to feeder canal which supplies water to the sumps of the pumps. A constant water level in feeder canal is maintained by means of down-stream water level controller.

Fig 33
IRRIGATION PLANTS of Nagykunság XII
Mezőhék No I II III and Tiszaföldvár No I-II
pumping units

M 1 50 000



The pumps are of vertical centrifugal type, all electrically driven and are mounted on the roof of sump. Two USN-150 type basic pumps and two-four USN-250 type main pumps having nominal capacity of 50 l/s and 200 l/s respectively, are connected in parallel to the common discharge pipe. One common priming pump and separate lubricating pump for each pump have been provided.

Energy supply to the pressure pumping center takes place through 20 kW net-work. One 1600 kVA capacity main transformer for pump operation and another 10 kVA for auxiliary utilization have been installed. The total installed capacity is 1185,57 kW, expecting maximum simultaneous electric demand of 900 kW.

Continuous measurement and registration of technological parameters such as volume of pumped water, amount of energy consumed, instantaneous and continuous water discharge and operating pressure of the pumps and water level in the sump etc. is performed by various measuring instruments. These instruments are necessary firstly to convey corresponding signals to the automatic control system which then regulate the pumps operation in a predetermined way, and secondly for registration of operating parameters and knowing water and energy consumption.

There are two air pressure tanks having $6,3 \text{ m}^3$ capacity and nominal operating pressure up to 1 MPa. These tanks help in smoothing the pressure waves occurring in the pipe-line as a result of sudden changes in water discharge and in replacing water losses in pipe-line networks occurring during the daily operation intervals in collaboration with cyclic operation of basic pumps. The water level in the air pressure tanks, changing according to the operation pressure is sensed continuously by pressure sensing element placed in it and is further conveyed to the pressure measuring and automatic instrumentation.

The subsurface installed pipe network consists of mains and submains. The submains are either 576 m or 666 m apart on the mains while the hydrant distance on the submain is 108 m, 96 m or 84 m. The pipe material used is asbestos cement and hard PVC. Various kind of fittings like air release valves water priming valves, sluice valves and pipe breakage safety valves at necessary points have been installed. The detailed design of pipe-line network of MEZŐHÉK I. irrigation unit is shown in Fig. 3.4.

Irrigation equipment on the field surface consists of mechanically transferable various types of laterals and are connected to one of hydrants for irrigation. The following types of lateral were provided to these sprinkler units: ALVSZ-87; ALVSZ-130; OBA and OBM; GO-240 and GO-252; VOLZSANKA; RAIN-ROLL; KF-120; CK-100; REGENGIGANT and FREGAT . The most important technical characteristics of different types of laterals are given in Appendix 3.2.

3.1.2. Basic operation data

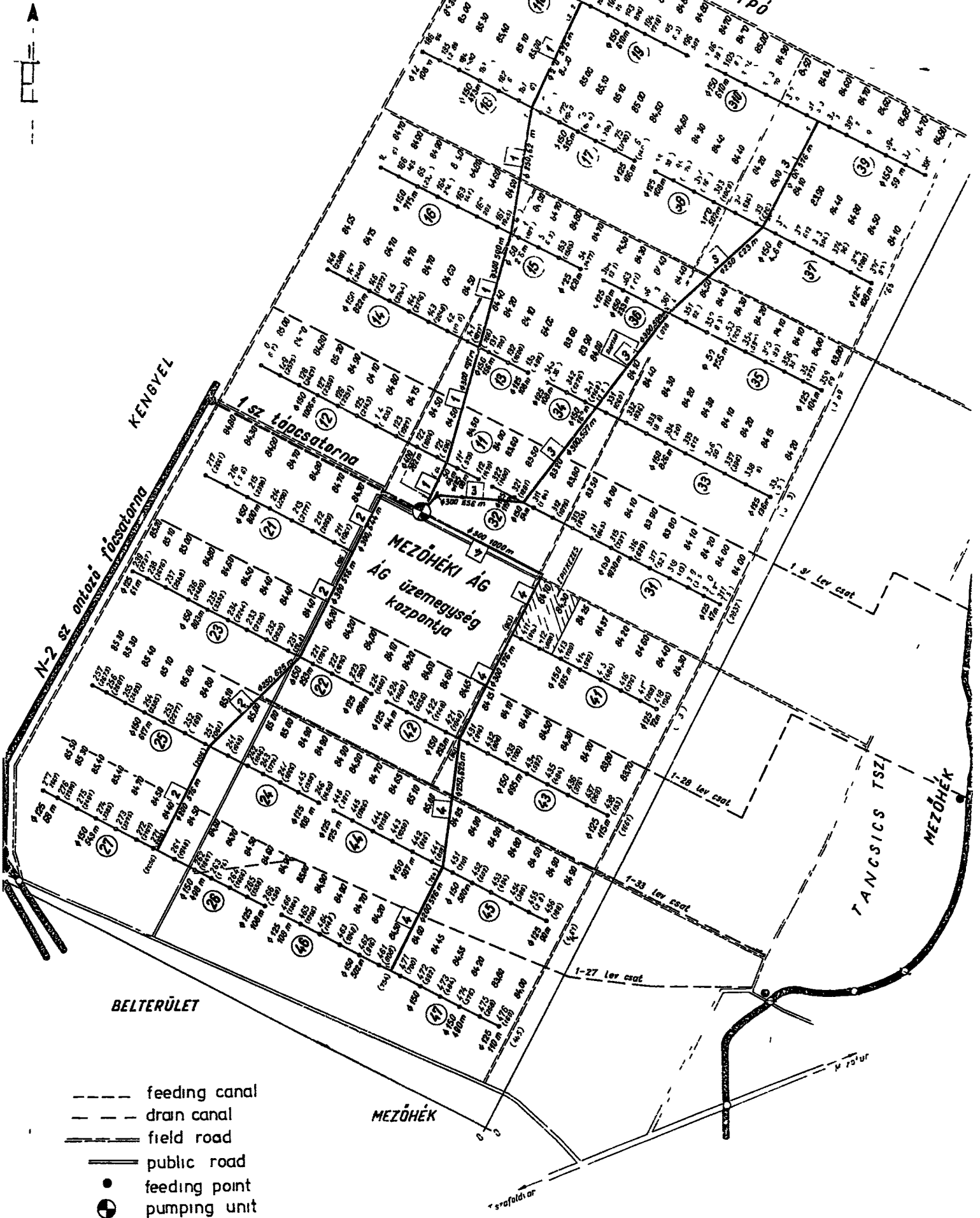
The following basic operation data was used for planning and designing of sprinkler irrigation units, taking into consideration the agro-climatic factors, soil type and probable cropping pattern of the district:

- total water application per year: 200 mm
- water application per irrigation setting: 60 mm
- irrigation period: 18 days
- daily working hours: 18 hours

Area to be irrigated at one time was planned as 1/3 of total installed capacity. The required minimum water pressure at the hydrant was designed to be 0,35 MPa at 26 l/s as an average water discharge. At the same time only one or two hydrants can be operated on each submain and the number of submains to be operated simultaneously on a given main should be decided by the water discharge capacity of the main.

FIG 34

IRRIGATION PLANT
MEZŐHEK No 1 Pumping unit



Taking into consideration the above basic data of planned irrigation practice, dimensioning of the complicated pipe network was effected substantially by using computer techniques. Which gave the most economical pipe diameter, the optimum layout of the main pipes leading to the minimum annual cost of operation. The computer techniques were also used for deciding the most economical site of the pump house, the optimum lifting head and the optimum size and shape of the irrigated land.

3.1.3 Automatically controlled operation of pumping units

The main task of pumps is to supply that amount of irrigation water as demanded by hydrants i.e. by sprinkler laterals connected to the hydrants. The pumps can be controlled either by manual or automatic way of operation. In later case the control is effected continuously on the basis of operating pressure, water discharge and electric power demand of the pumps.

In case when there is no irrigation or relatively low water demand on the field, the system pressure is assured by the basic pumps. The operation of basic pumps is controlled by the pressure transducers placed in the air pressure tank, and connected relays. During an irrigation season the water pressure in the pipe network is maintained constant between basic pressure of 0,75 MPa and 0,93 MPa. During this period if the pressure drops below 0,75 MPa, then B1 pump starts and stops when 0,93 MPa is reached.

In case when there is irrigation and if the water demand is more than the capacity of B1, resulting in to reduction of pressure in the pipe network, B2 pump starts. If the pressure increases the B2 stops and even if the pressure further increases due to cease of irrigation B1 also stops. On the other hand if irrigation demand is higher than what B1 and B2 could satisfy, pressure in the networks reduces and when it reaches to 0,69 MPa, the first main pump /M1/ starts, at the same time B1 and B2 are switched off. Further increase of irrigation water demand will start the remaining main pumps /M2, M3, M4, M5/

according to the water discharge demand of laterals and pre-selected operating sequence. If water demand is so large that all the main pumps are incapable of satisfying the demand, then parallel to the automatic operation of main pumps basic pumps can be put into operation by manual switching-on to fulfill the water demand of the laterals. When the irrigation is discontinued by closing hydrants the pumps will stop in the reverse sequence.

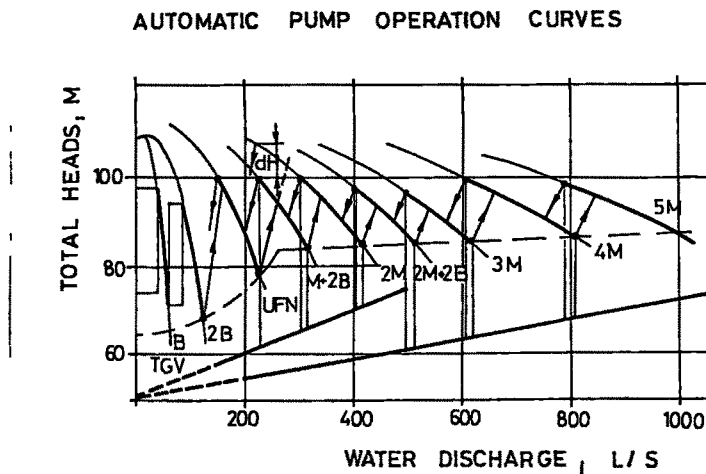


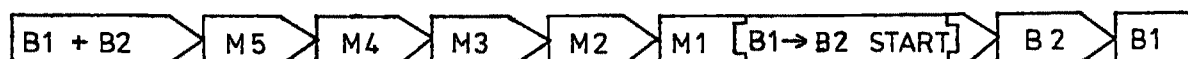
Fig. 3.5

The typical pump operation characteristics of the pumping unit having two basic pumps and five main pumps are shown in Fig. 3.5, while "start" and "stop" sequence is sketched below when the main pump starting sequence selected is 1-2-3-4-5:

- pump start sequence



- pump stop sequence:



The automatic control system in addition stops the operation of all pumps when:

- the network pressure reduces below 0,4 MPa due to pipe breakages or other reasons;
- the water level in suction sumps drops below the minimum level;
- the electric peak period commences, and restarts the operation at its termination.

Sound and light signals are produced in case of any undesired or faulty operation.

3.2 Overall energy consumption data for the region

The comprehensive energetical data for orientation and overall view about irrigation energy intensiveness was collected from Tisza Regional Water Work and Water Management company /TRVVV/ stationed at Szolnok, being the largest irrigation management company in the country and responsible also for operation of largest part of TISZA-II irrigation project and for selected NK-XII. irrigation area, too, including the examined six irrigation pumping units in MEZŐHÉK-TISZAFÖLDVÁR district.

3.2.1 Irrigation area, water and energy consumed

Based on statistical data available at Szolnok TRVVV company, the total and actual irrigated area, consumed water and energy for irrigation purposes and its cost is given in Appendix 3.3 for the last six years. The summarized figures includes both primary and secondary lifting and sprinkler irrigation pumping energy and cost requirements as it was not possible to separate them according to pumping methods. The most important overall average values of specific parameters are shown in Table 3.1

Overall irrigation energy characteristics
of Szolnok TRVVV company

Table 3.1

Year	Electric operated pumps			Diesel operated pumps		
	kWh/m ³	kWh/ha	Ft/kWh	g/m ³	kg/ha	Ft/kg
1974	0,069	311,9	0,64	34,67	111,1	4,68
1975	0,055	364,2	0,75	16,98	80,1	4,68
1976	0,090	427,0	0,86	17,82	54,3	5,39
1977	0,082	427,5	0,85	17,29	58,2	5,39
1978	0,063	486,9	1,36	22,43	54,6	5,39

It can be concluded from the above figures that the average energy demand influenced by the ratio of water lifting and sprinkler irrigation pumping, have been changing between 0,050-0,090 kWh/m³ and 17,0-35,0 g/m³ for electric and diesel operated pumps, respectively. The specific irrigation energy related to irrigated land /311,9-486,9 kWh/ha and 54,3-111,1 kg/ha resp./ is considerably high compared to energy requirement of other agricultural processes. The overall average price of energy has been steadily increasing, especially during the last two years.

3.2.2 Energy utilization by pumping units

Apart from the overall energetical data of SZOLNOK, TRVVV company the more detailed operation characteristics of all pumping units have been collected for 1978 and 1979 years, covering the area of three Directorships called SZOLNOK, DEBRECEN, and GYULA. The pumping units are grouped according to energy source, as ELECTRIC and DIESEL operated, and their destination, as PRIMARY LIFTING PUMPS, SECONDARY LIFTING PUMPS and SPRINKLER IRRIGATION PUMPS. Starting from actual yearly water discharge, operation hours and energy consumption the specific energy demand /kWh/m³ and g/m³/ was calculated /Appendix 3.4 - Appendix 3.7/.

On the basis of data related to 57 large pumping units of agricultural purposes including 157 electrically operated

and 101 diesel operated pumps of high capacities the specific energy utilization of agricultural water lifting can be characterized by the summarized figures given in Table 3.2.

Specific energy utilization of
agricultural water lifting

Table 3.2

		Energy consumption	Specific energy average	Specific energy demand limits
<u>ELECTRIC OPERATED</u>		MWh	kWh/m ³	kWh/m ³
- primary	1978	2761	0,0154	0,0147-0,0645
	1979	3890	0,0238	0,0114-0,0498
- secondary	1978	1803	0,0295	0,0103-0,0223
	1979	402	0,0174	0,0102-0,0248
- sprinkler	1978	2244	0,318	0,209 -0,598
	1979	5505	0,299	0,209 -0,400
Total	1978	6808	0,025	-
	1979	9797	0,048	
<u>DIESEL OPERATED</u>		t	g/m ³	g/m ³
- primary	1978	271,8	5,81	4,08 - 10,68
	1979	566,7	6,61	4,41 - 9,01
- secondary	1978	179,1	5,71	4,13 - 9,95
	1979	181,9	6,61	3,40 - 10,74
- sprinkler	1978	43,2	78,20	78,20
	1979	47,7	77,33	77,33
Total	1978	491,1	6,27	-
	1979	796,3	6,99	

The average electric energy demand for water lifting and sprinkler irrigation at SZOLNOK TRVVV company as an average consumption of 76 lifting and 81 sprinkler irrigation pumps have been found as 0,015-0,030 kWh/m³ and 0,30-0,32 kWh/m³, respectively. The same figures for 91 lifting pumps and 10 sprinkler irrigation pumps were 5,7-6,6 g/m³ and 77,3-78,2 g/m³ respectively during 1978 and 1979 years, operated by diesel engines.

3.3 Energetical survey of MEZŐHÉK-TISZAFOLDVÁR irrigation plant

It is evident from related literature and overall view of energy consumption and energy costs of irrigation that the most energy intensive and expensive field is the operation of irrigation plants covering 800-1500 ha of cultivated land and having many irrigation pumping units of high capacity. In the framework of twenty years' irrigation development programme some thirty these type of units have been realized, total sprinkler irrigation capacity of which is 20500 l/s and their installed electric power demand is 29,5 MW /Appendix 3.8/. Among these establishments the MEZŐHÉK-TISZAFOLDVÁR irrigation plants, selected for my research field experiments, having 4236 l/s and 6,4 MW total discharge capacity and power demand respectively are the most up-to-date ones, supplied with instrumentation and automatic control of high level.

3.3.1 Overall energetical data of MEZŐHÉK-TISZAFOLDVÁR irrigation plant

For the six irrigation pumping units which constitutes the MEZŐHÉK-TISZAFOLDVÁR irrigation plants, similar but more comprehensive energy and energy cost, and water consumption data were collected for longer period /Appendix 3.9/. From the basic data /water discharge, operation hours, energy consumption and energy costs/ the specific water application /m³/ha/, energy consumption /kWh/ha and kWh/m³/, and specific energy costs /Ft/ha and Ft/m³/ were calculated. The most important results are collected in Table 3.3.

Specific energy consumption at MEZŐHÉK-TISZAFOLDVÁR irrigation plants

6 plants, 7456 ha

Table 3.3

Year	Irrigated land ha	Water appl. m ³ /ha	Specific energy consumption		Specific energy cost		
			kWh/ha	kWh/m ³	Ft/ha	Ft/m ³	Ft/kWh
1976	6344	1192	365	0,306	392	0,329	1,07
1977	4711	1163	372	0,320	330	0,284	0,87
1978	4735	671	200	0,299	451	0,672	2,25
1979	6998	1515	355	0,234	446	0,295	1,26
1980	4011	896	280	0,313	509	0,847	1,82
Average	5356	1087	314	0,294	425	0,485	1,45

The average utilization factor based on irrigated land of six irrigation plants during 1976-1980 period was 71,8 % changing from 53,7 % to 93,8 % depending upon weather conditions. The capacity utilization factor based on planned water discharge $11 \cdot 10^6 \text{ m}^3/\text{year}$ was higher in 1979, 93,0 % and lower in 1978, when it was only 27,9 %. The average specific energy cost of water supplying was changing among considerably wide limits $/0,29-0,85 \text{ Ft/m}^3/$, depending basically upon the yearly water discharge $/\text{Table 3.3}/$, and in case of individual irrigation pumping units $/\text{Appendix 3.9}/$ even among greater limits $/0,247-1,221 \text{ Ft/m}^3/$, as it is shown in Fig.3.6 . As the examined six sprinkler irrigation plants are quite similar regarding their construction and size, the average electric energy was changing between narrower limits $/0,23-0,32 \text{ kWh/m}^3/$. The increasing of specific energy cost of water was caused mainly by specific cost of electricity being very sensible for utilization factor of pumping plant i.e. that of electric power demand. According to the present tariff systems in Hungary if the utilization factor is nearly 100 percent some 1,- Ft/kWh $/\text{or } 0,30 \text{ Ft/m}^3/$ specific cost of electricity could be realized, but it may be three to four times higher if the utilization factor drops down to 20-25 percent $/\text{Fig. 3.7}/$.

3.3.2 Seasonal characteristics of irrigation energy demand

The specific characteristics of irrigation water demand and technology as well as the general features of electric energy supplying gives the reason of overall review of seasonal characteristics of energy utilization in examined irrigation pumping units. According to the present practice in Hungary irrigation season starts in April and comes to its end in September, though in 1978 and 1979 considerable amount of water was used in September and October for filling of soilprofile with water for next cropping season.

As it is evident from specific figures in Appendix 3.10-3.12 elaborated only for MEZŐHÉK I-III. pumping units the monthly average of specific energy and energy cost parameters

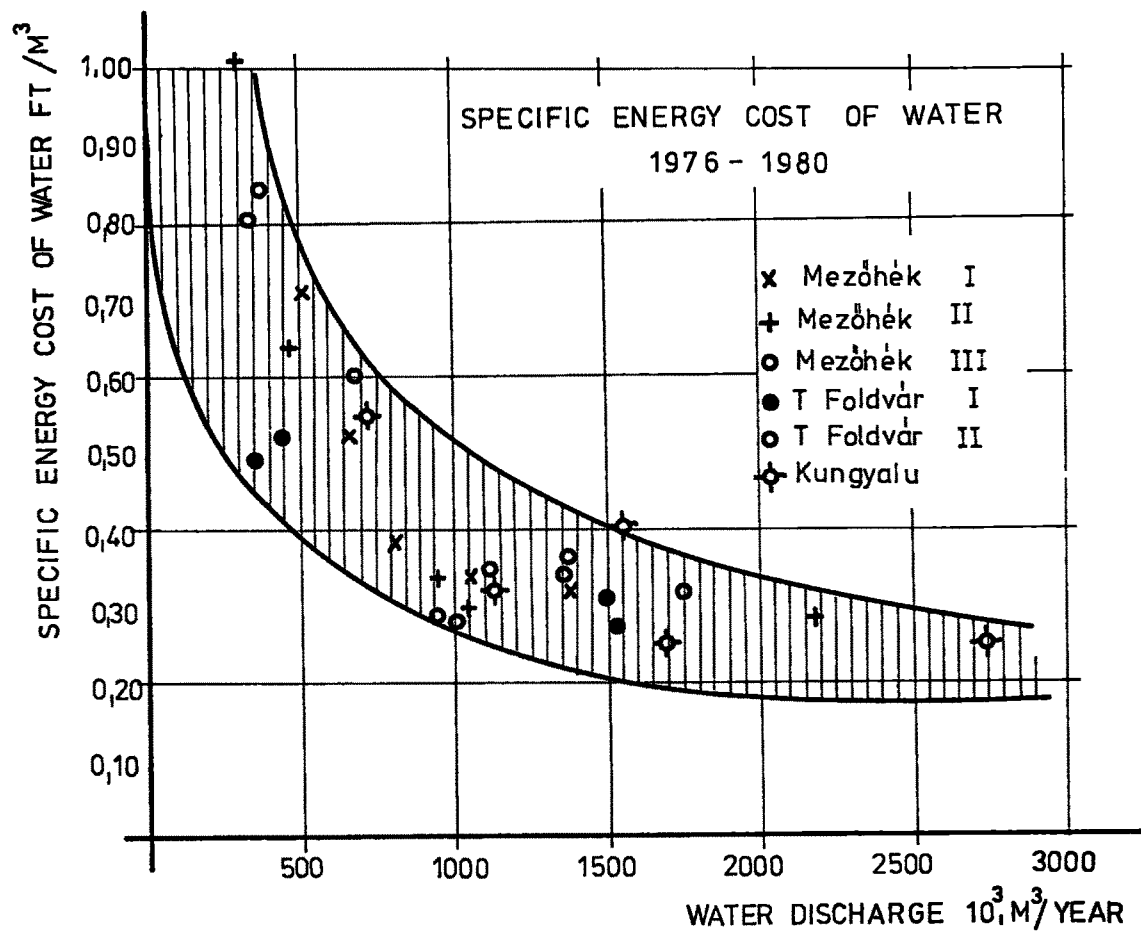


Fig. 3.6

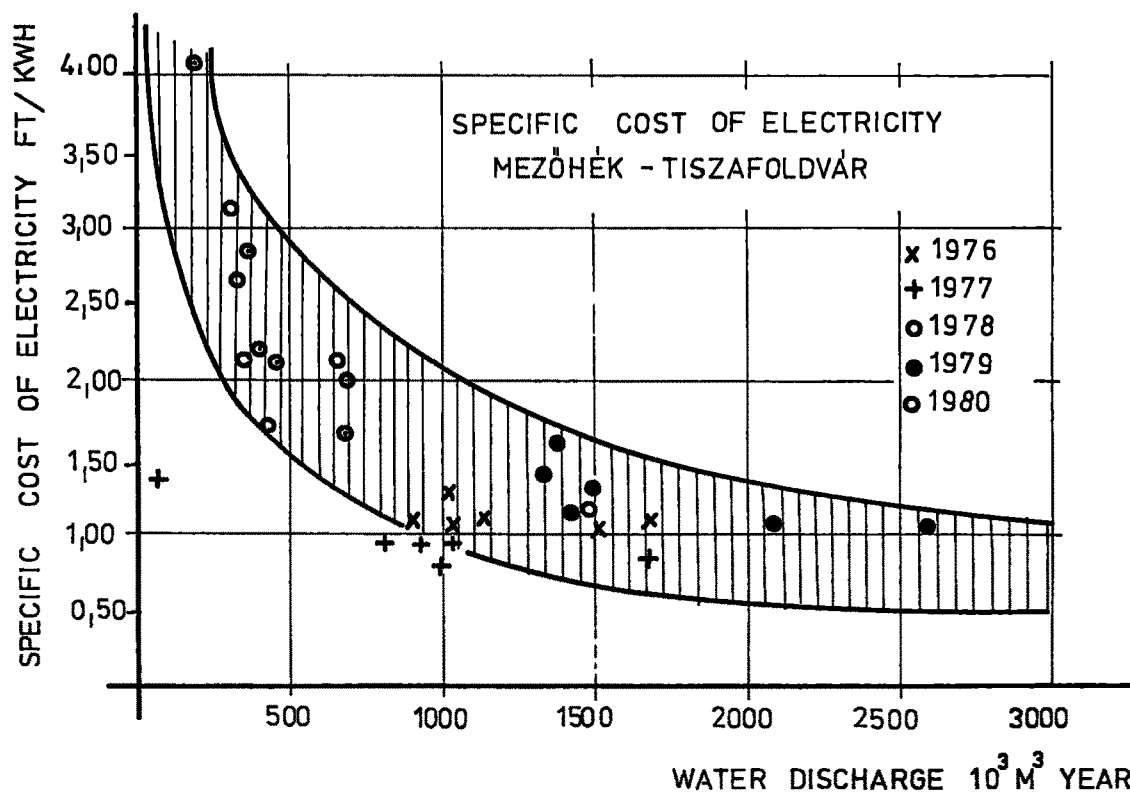


Fig. 3.7

changes between very large limits around the yearly average /Table 3.4/.

The spreading of monthly average energy and energy cost parameters of MEZOHEK I-II-III. irrigation units

Table 3.4

Irrigation unit	Specific energy kWh/m ³		Specific cost Ft/kWh	
	average	range	average	range
MEZŐHÉK I. 1978	0,327	0,26-0,39	2,16	1,6-3,3
1979	0,274	0,21-0,39	1,18	0,9-2,0
1980	0,330	0,16-1,31	1,62	1,3-12,5
MEZŐHÉK II. 1978	0,339	0,22-0,67	3,14	1,6-6,5
1979	0,247	0,15-0,40	1,13	0,9-1,7
1980	0,297	0,27-1,91	2,15	1,3-3,9
MEZŐHÉK III. 1978	0,295	0,16-0,44	2,06	1,3-8,6
1979	0,230	0,15-0,35	1,44	1,1-3,9
1980	0,290	0,25-1,04	2,80	1,6-4,5

The montly average energy cost of water-pumping in examined three irrigation units varied, as follows /in Ft/m³/:

	MEZŐHÉK I.	MEZŐHÉK II.	MEZŐHÉK III.
1978.	0,56-1,01	0,50-2,17	0,41-2,62
1979.	0,19-0,57	0,13-0,58	0,16-1,39
1980.	0,33-2,15	0,32-5,29	0,35-5,27

The average energy cost depends basically upon the wing three factors:

- utilization of pumping capacity,
- utilization of electric power demand,
- specific price of power and energy.

The nominal pumping capacity of the three units, are follows: 800 l/s, 840 l/s and 800 l/s, which represent so 6,22 million m³ total capacity taking into consideration months irrigation season and 20 days monthly operation v

18 hours working days. The planned water was 1,3; 1,7 and 2,0 million m³ per year for the three units, respectively. The installed total pump capacity was substantially over-calculated, thus the yearly utilization of nominal capacity was very low /in percent/:

	MEZŐHÉK I.	MEZŐHÉK II.	MEZŐHÉK III.
1978.	10,3	4,8	11,5
1979.	23,2	35,5	21,9
1980.	11,5	7,6	5,6

Comparing the real water discharge to the planned water demand the yearly utilization factor changes between large limits %/:

	MEZŐHÉK I.	MEZŐHÉK II.	MEZŐHÉK III.
1978.	49,4	17,5	35,9
1979.	110,8	129,7	68,1
1980.	54,8	27,8	17,6

According to the present energy tariff systems in Hungary the power cost /45,- Ft/kW or 22,50 Ft/kW per month/ should be paid in advance, and only the energy cost /1,30 or 1,70 Ft/kWh day and 0,70 Ft/kWh night tariff/ is counted after the actual consumption. In this way the average energy cost is very sensible for the determination of power /kW/ demand. For the examined three irrigation units the maximum power capacity /800 kW/ was contracted, thus some 20000,- Ft had to be paid monthly, even there was no irrigation demand at all. These are the main reasons of the surprising facts demonstrated in Appendix 3.10-3,12, i.e. the monthly average price of electricity sometimes can reach 5,50-8,60 Ft/kWh and, the energy cost of water supplying 2,60-5,30 Ft/m³ which values are much higher than the reasonable averages /Table 3.4/ or the desirable minimum values 1,30-1,50 Ft/kWh and 0,35-0,45 Ft/m³ belonging to high capacity and electric power utilization factors.

All the data collected on company level and at the irrigation plants and pumping units verifies the more and more importance of energy economy on the field of irrigation, too.

3.4 Specific energy consumption characteristics of MEZŐHÉK-TISZAFOLDVÁR pumping units

During the irrigation season of the year 1979. daily measurements of the most important parameters were organized for the six pumping units in general and in 1980 for MEZŐHÉK I. and MEZŐHÉK II. units in particular. The specially prepared proformas /Appendix 3.13-3.19/ were used and filled up with the help of pump operators of concerned unit. The proformas consist the operation data of 4 Main pumps and 2 Basic pumps, namely their operation hours separately and the consumed electric energy during day, night and peak hours period, as well as the scale of continuous water discharge meter for all the pumping units.

The installed electromagnetic induction type water flow measuring device connected to the common discharge main was used as water meter /Fig. 3.8/, while the pressure and water discharge meter of registration type indicated the change of operation characteristics, continuously /Fig.3.9/. For measuring electric energy and operation hour conventional installed meters were used. For comparing the change of pipe-line pressure, water discharge and belonging electric power demand a registration type of kW meter was installed specially for the purposes of my research programme. The tables containing the numerical data and strips with diagrams were collected and processed by the help of Computer Centre of Agricultural University of Gödöllő using routine mathematical statistical programmes for ODRA-1204 type computer.

3.4.1 Long-term energetical parameters of irrigation units

Using the whole series of tables representing nearly the five months operation characteristics of six irrigation units - several of which are presented in Appendix 3.13 through

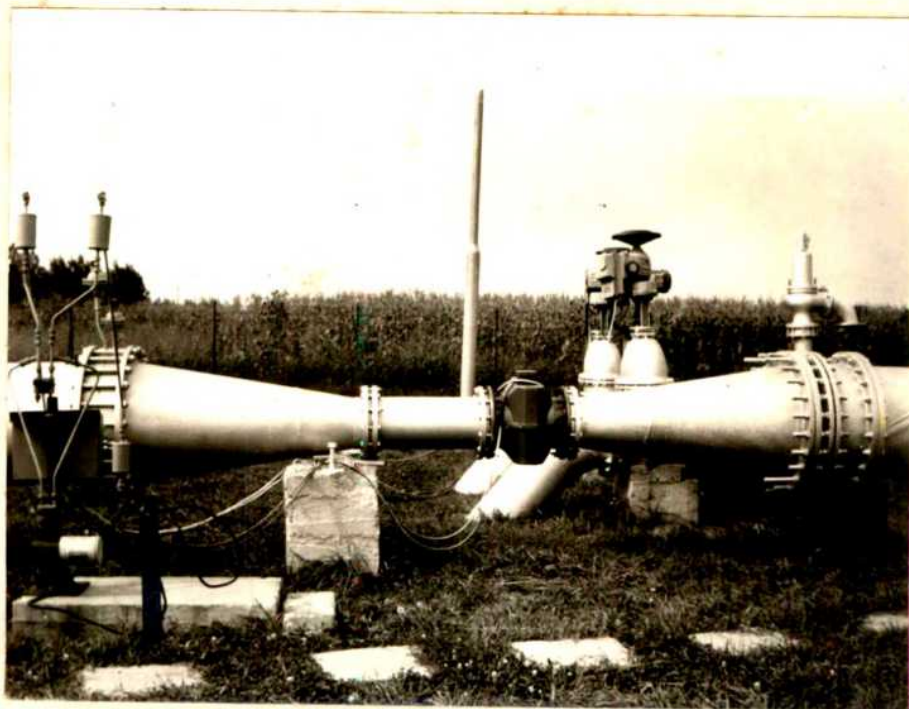


Fig.3.8 Electromagnetic induction type water flow measuring device connected to the common discharge main



Fig.3.9 Instrumentation panel for indicating various parameters



Appendix 3.19 - the available data sheets for processing were selected. Some 16 irrigation period at various pumping units have been analysed. The intermediate results of processing are introduced in Appendix 3.20-3.26. After summing up the daily water discharge and energy used the daily and periodical average of specific energy consumption was calculated. The average energy demand depends basically upon the actual pressure of the system i.e. upon the distance of irrigated land from pumping centre, resistance and losses in pipe network etc. The average irrigation parameters of various selected periods, length of which has been changed from 6 to 22 days, are summarized in Table 3.5.

Average daily energy consumption and water discharge of sprinkler irrigation units

Table 3.5

Irrigation unit	Irrigation period	Energy used /average/ kWh/day	Water pumped /average/ m ³ /day	Average specific energy kWh/m ³
MEZŐHÉK I.	1979.JUNE	3676	8691	0,47
	JULY	5492	2486	0,50
	SEPT.	1417	2802	0,54
	1980.JULY	3261	12498	0,26
	AUG.	2781	7876	0,39
	SEPT.	1123	2555	0,44
MEZŐHÉK II.	1979.JUNE	6124	17908	0,33
	JULY	2907	8865	0,43
	AUG.	3415	5565	0,65
	SEPT.	2520	8844	0,33
	1980.JULY	2351	14735	0,17
	AUG.	2344	18255	0,13
T.FÖLDVÁR I.	1979.JUNE	3553	20234	0,20
T.FÖLDVÁR II.	1979.JUNE	1940	14177	0,22
KUNGYALU I.	1979.JUNE	6482	25047	0,25
	JULY	3780	13258	0,29

The specific energy requirement /SER/ based on above field experiment were calculated, as follows:

$$\text{SER} = \frac{400 \cdot [E_e - E_b]}{40 \cdot [V_e - V_b]} \quad [\text{kWh/m}^3]$$

where: E - energy consumed /kWh/; V - volume of water pumped /m³/; b and e - suffixes indicating the beginning and end of operation; 40 and 400 - multiplying factors for kWh and watermeter respectively

The average daily values of water pumped, energy used and specific energy demand for MEZŐHÉK I. and MEZŐHÉK II. irrigation units are given in Fig.3.10 and Fig. 3.11 .

3.4.2 Short-term energetical characteristics of irrigation units

During the irrigation season of the year 1980 at MEZŐHÉK-I. pumping unit I carried out more detailed measurements of irrigation and energy utilization parameters, in order to follow the real irrigation practice and operational characteristics of the pumping unit. Hourly readings of cumulative discharged water volume and electric energy consumption, instantaneous water discharge and pressure were noted in proformas prepared for this special purpose /Appendix 3.27 - Appendix 3.29/.

At the same time the discharge-pressure diagrams from installed recording instrument and electric power diagram from recording instrument installed for this special purpose were continuously checked /Fig. 3.12 - Fig.3.14/. Any change in the operation i.e. starts and stops of pumps etc. were also noted.

Simultaneously, field irrigation data i.e. number of operating hydrant, type and number of laterals in operation, type and number of sprinklers on each lateral and duration of operation of individual lateral were also collected /Appendix 3.30/. The short-term examination of energetical characteristics of MEZŐHÉK-I. unit was some two weeks long from 26. JULY 1980 till 12.AUG.1980. From this series of measurements

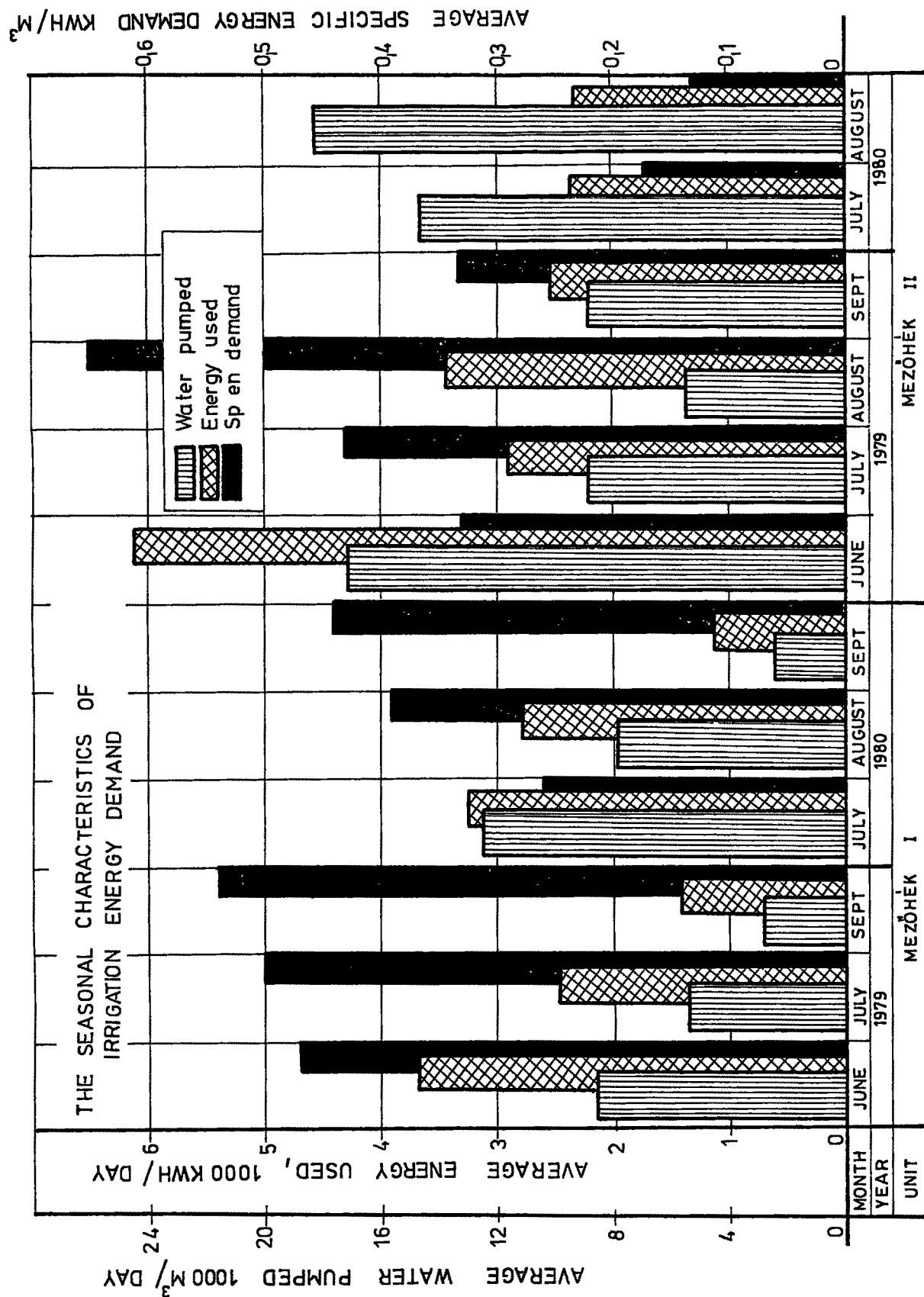


Fig. 3.10

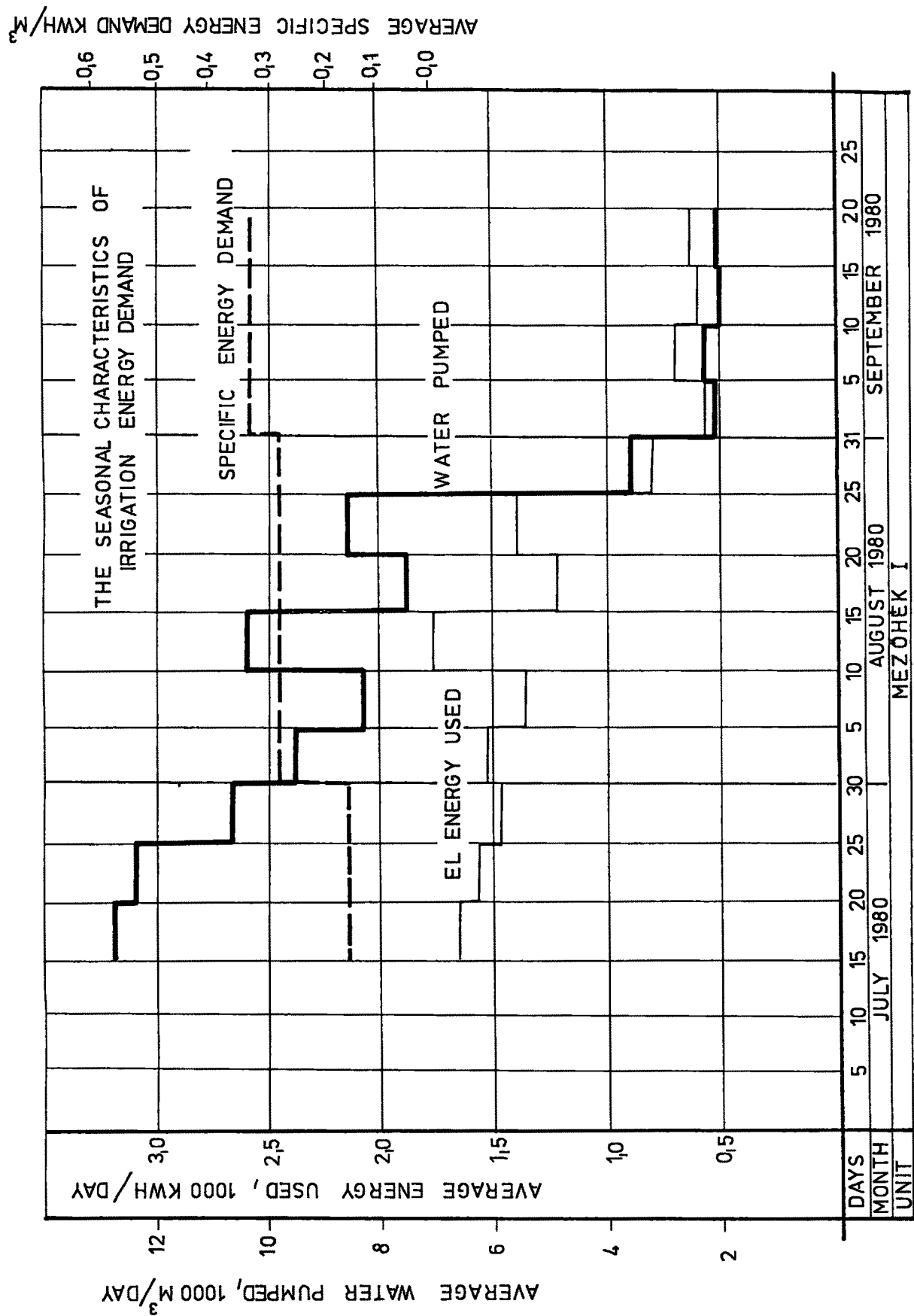


Fig. 3.11

MEZOHEK -I pumping unit

7th AUGUST 1980

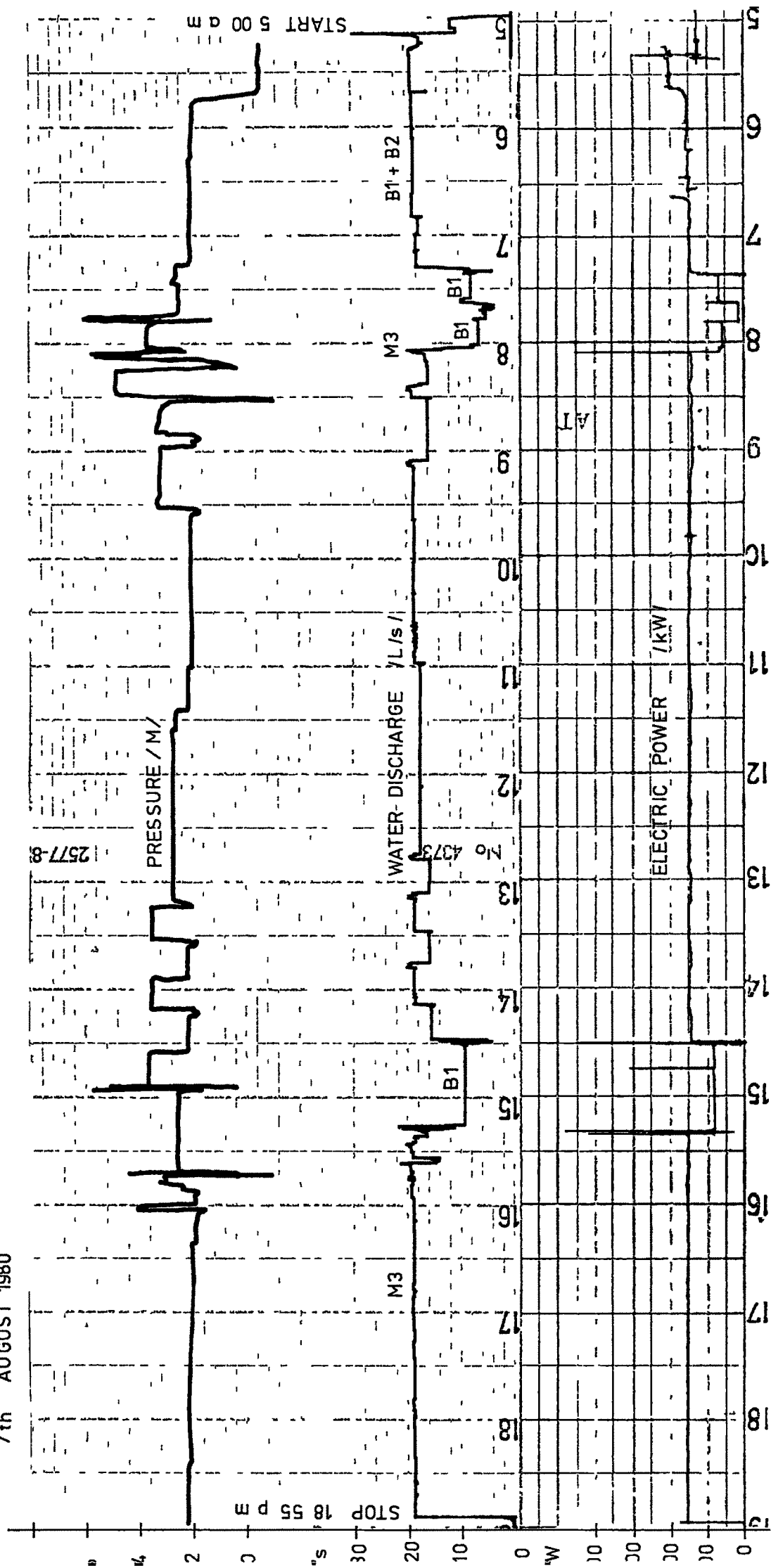


Fig 3 12 Pressure , water discharge and electric power diagram

MEZŐHÉK - I pumping unit

8th AUGUST 1980

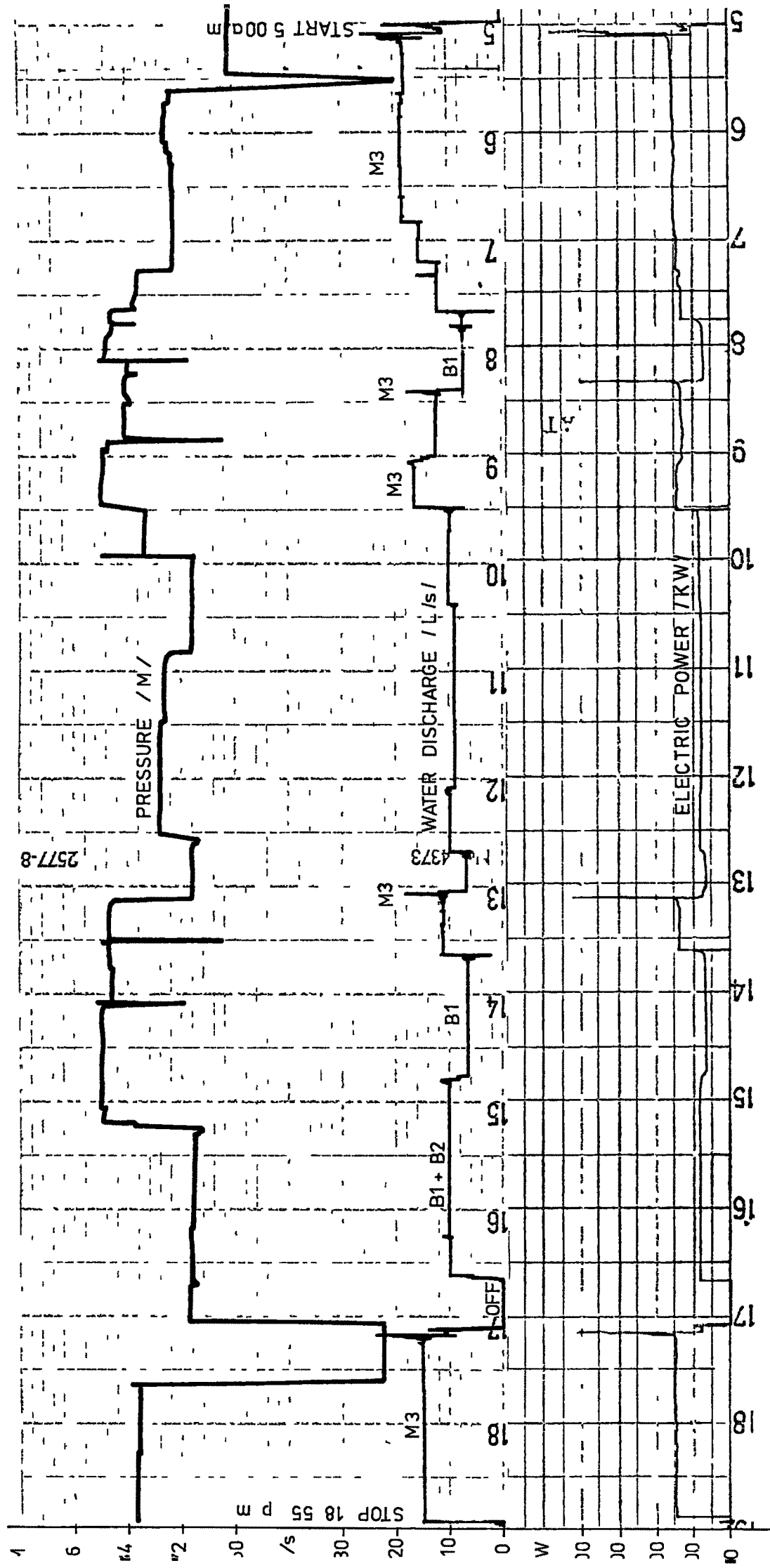


Fig 3 13 Pressure , water discharge and electric power diagram

MEZŐHÉK I pumping unit
12th AUGUST 1980

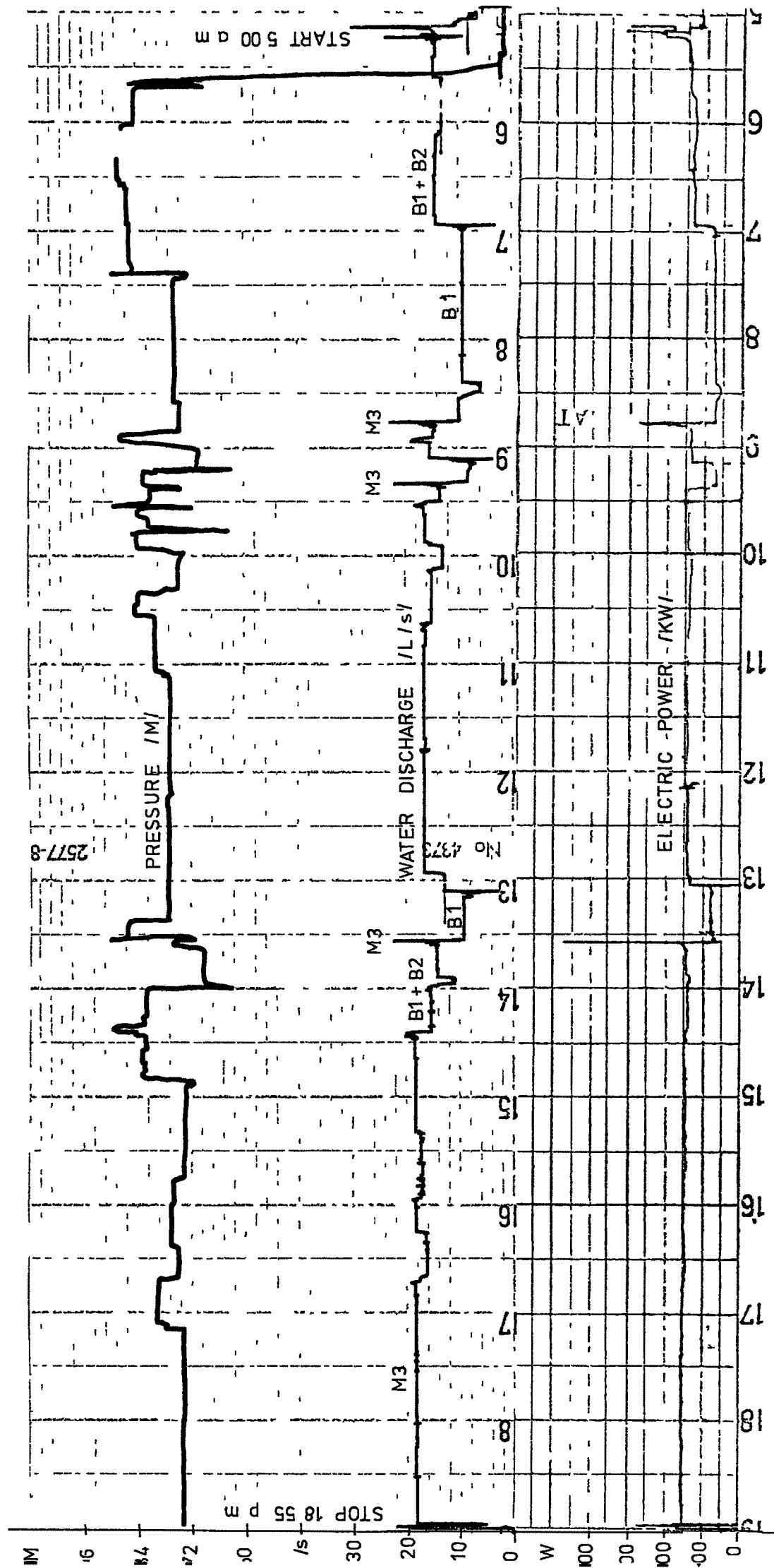


Fig 314 Pressure, water discharge and electric power diagram

only the data of three days /7th, 8th and 12th of AUG.1980./ are represented in my thesis as examples.

The daily water discharge, pressure and electric power diagrams were evaluated with the help of X-Y digitizer which gave the values in the form of punched tapes. The basic data was fed into ODRA-1204 computer which performed the necessary calculations by the short computer programme /Appendix 3.31/ written specially for this purpose. The results for the selected days are given in Appendix 3.32 - Appendix 3.34. Apart from the average water discharge and pressure the specific energy consumption /kWh/m³/ and pumping efficiency factor /per cent/ were calculated.

As it can be seen from Table 3.6, the average pressure in the system proved to be smooth enough for proper operation even though the water discharge was changing between comparatively wide limits. The specific energy consumption was some 0,33 kWh/m³ on a daily average while the pumping efficiency varied from 50,81 to 67,77 per cent, with an average value of 61,63 percent. Which is satisfactory situation from energy consumption point of view. Although pumping unit efficiency of main pump is expected around 70 percent.

It can be noticed from Appendix 3.32 - 3.34 that when the pumps operate around their nominal capacities, the pumping unit efficiency is also high, giving optimum values of specific energy consumption. The specific energy consumption is higher when Basic pumps are operated than that of Main pump's operation. This is due to lower pumping unit efficiency of the Basic pumps compare to main pumps.

The results of computer calculation of specific
energy consumption and pump efficiency

Table 3.6.

EVALUATION OF DISCHARGE-PRESSURE DIAGRAM

PUMPING UNIT : MEZOHEK I

DATE: 7. AUGUST, 1980.

TIME HOURS	AVERAGE DISCHARGE LIT/SEC	AVERAGE PRESSURE MPA	SPECIFIC ENERGY CONSUMPTION KWH/CUM	PUMPING UNIT EFFICIENCY PERCENT
5- 6	195.74	0.64	0.318	54.70
6- 7	203.67	0.73	0.310	63.73
7- 8	117.73	0.81	0.375	58.95
8- 9	185.62	0.77	0.329	63.47
9- 10	207.11	0.72	0.312	63.03
10- 11	205.39	0.72	0.299	65.74
11- 12	193.36	0.76	0.313	65.75
12- 13	193.36	0.77	0.329	63.92
13- 14	197.66	0.74	0.311	64.97
14- 15	141.80	0.76	0.348	59.71
15- 16	194.22	0.70	0.314	61.00
16- 17	220.00	0.71	0.304	63.18
17- 18	220.00	0.71	0.311	61.83
18- 19	193.36	0.63	0.298	57.57

With the help of basic data the Table 3.7 was formed to follow the main pipe capacity utilizations during a randomly selected irrigation practice. The data in Table 3.7 was further used to construct Fig.3.15.

Main pipe capacity utilization
Duration: 5. to 13. AUG. 1980

MEZŐHÉK-I.

Table 3.7

Unit	Planned water discharge l/s					Dates of operation	
	200	160	120	80	40		
<u>Main 1.</u>							
-actual l/s	110	90	90	90	46	5,6,7,8,11	
-utiliza- tion %	55,0	56,2	75,0	112,5	115,0		
-actual l/s	66	46	46	46	46	8, 12, 13	
-utiliza- tion %	27,5	28,7	38,3	57,5	115,0		
<u>Main 2.</u>							
-actual l/s	-	20	-	-	-	11,12,13	
-utiliza- tion %	-	12,5	-	-	-		
<u>Main 3.</u>							
-actual l/s	86	44	44	-	-	5,6,7,8,11	
-utiliza- tion %	42,0	27,5	27,5	-	-		

Owing to changing cropping pattern and location of irrigated area, the irrigation water demand and water discharge through a given main pipe and submain pipes changes within very wide limits. Consequently the main pipe utilization may be as low as 12,5 percent on certain occasions. This situation is favourable from energy demand side, but unfavourable on the side of fixed annual cost.

3.4.3 Hydrant operational characteristics

In order to understand the real pump-irrigation operational interaction and its relation with energy demand measurements of pressure and water discharge of randomly selected hydrant were carried out. The lateral type operating at the hydrant was VOLZSANKA, 530 m long and fitted with 24 TISZA-II. type

WATER FLOW CHARACTERISTICS IN MAIN PIPES
MEZŐHÉK -I 5-13 AUG 1980

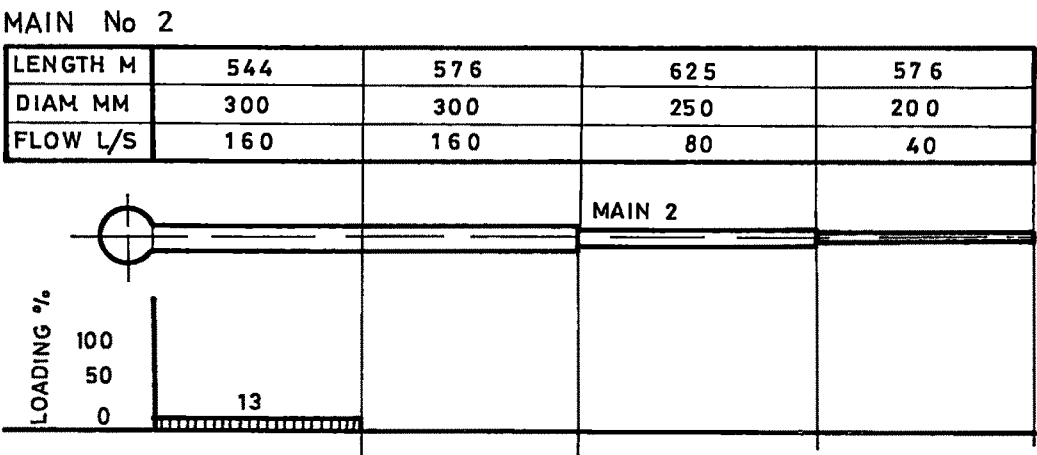
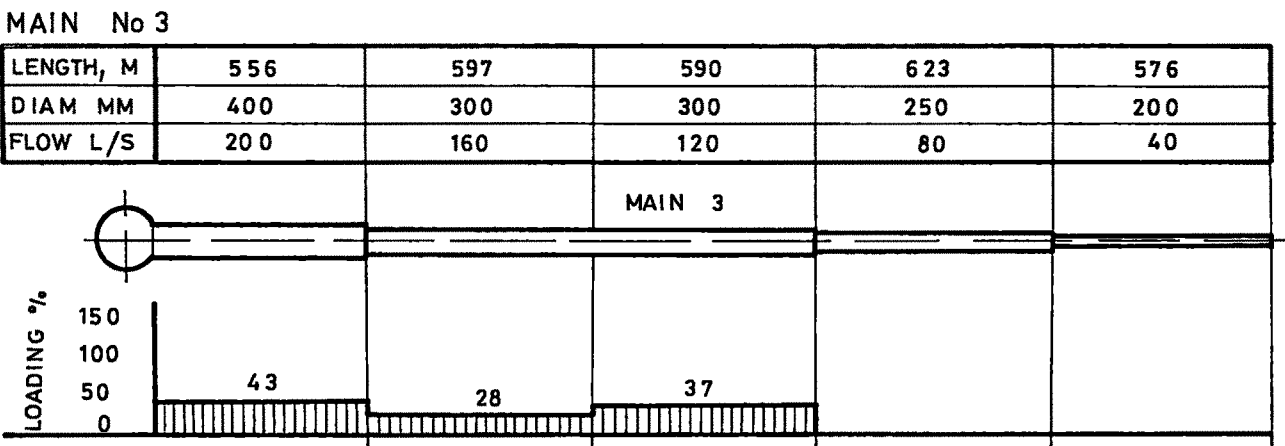
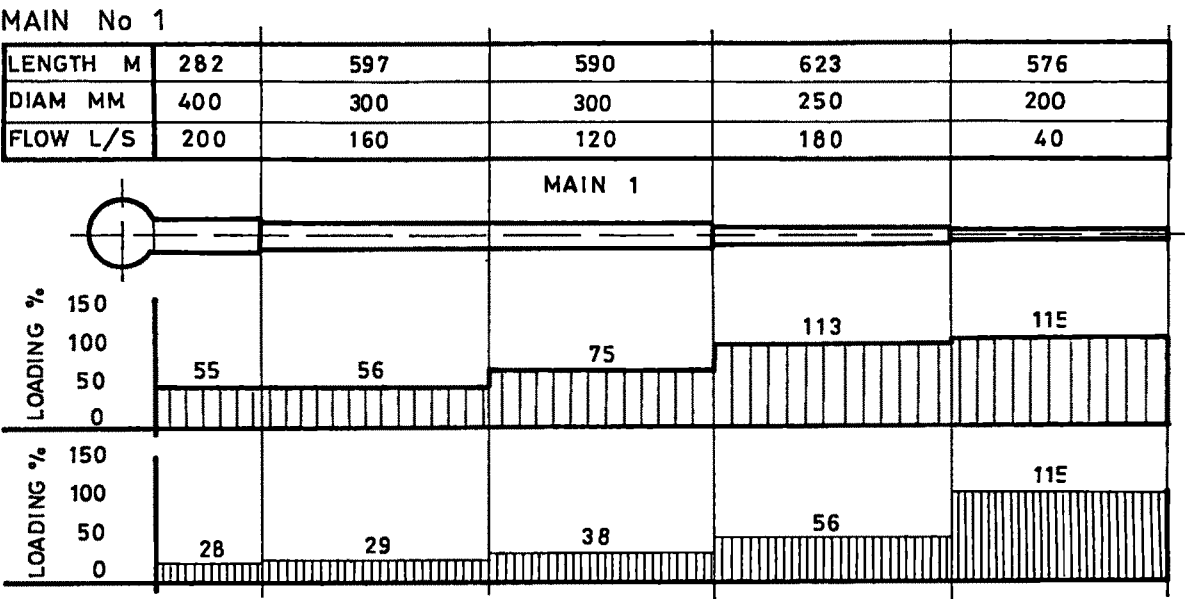
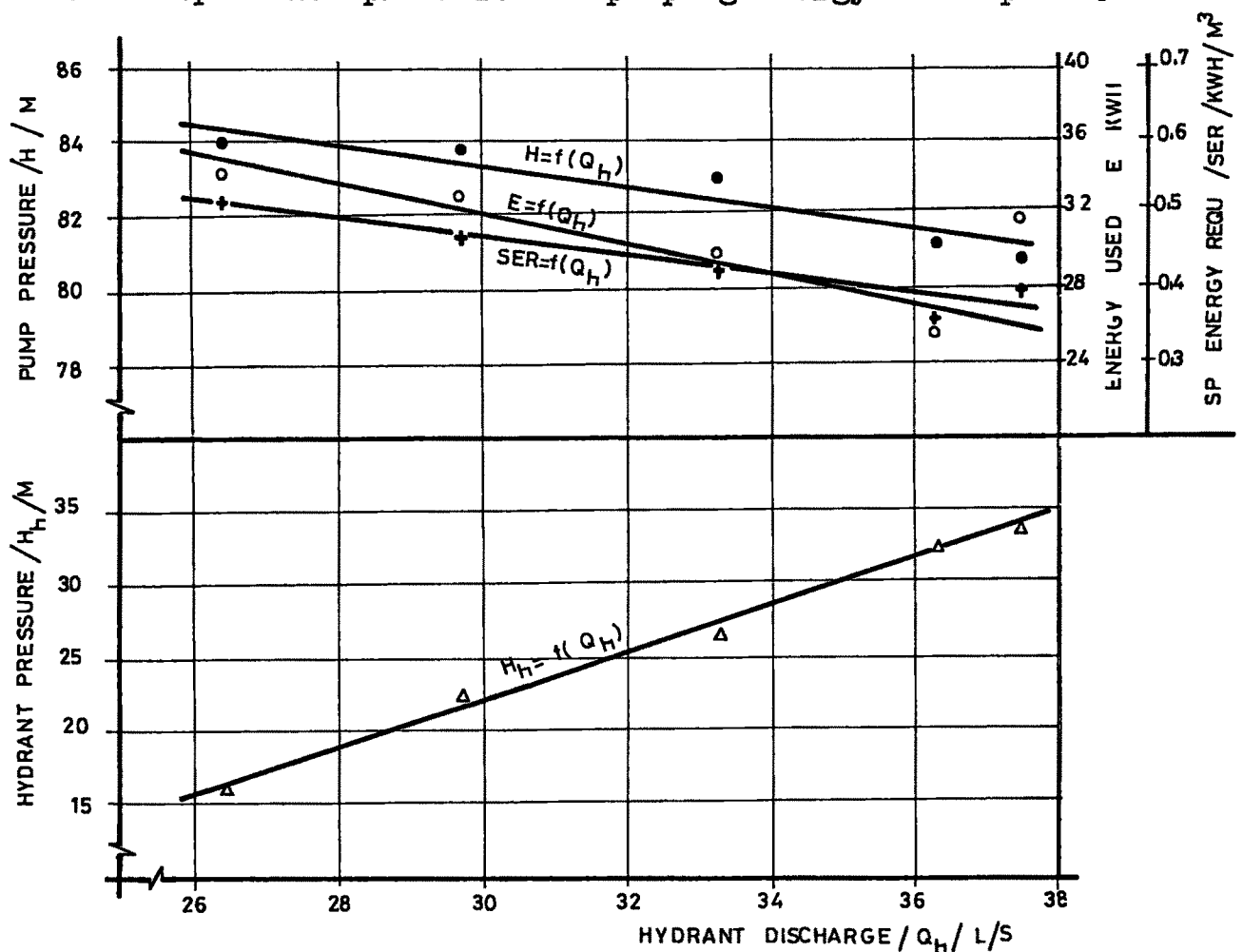


Fig 3 15

of sprinklers. The standard orific meter ND:150 mm was used to measure the water discharge, and pressure gauges to measure the pressure near hydrant and first and last sprinklers on the each lateral.

During operation, hydrant valve was manipulated so as to have a throttling affect. Simultaneously reading of pump water discharge, volume, pressure, electric consumption were also noted in pumping center. Unified proformas were used for noting the pump operation parameters /Appendix 3.35- Appendix 3.36/. During the two days field experiment carrying out readings in every quarter of hour. The measurement for the same hydrant were repeated three times, while for evaluation purposes the average values of observations were used, and are summarized in Table 3.8. The procedure for calculation of hydrant water discharge and pressure is enumerated in Appendix 3.37. Values from Table 3.8 were utilized to construct the Fig. 3.16 showing the relation between hydrant discharge, pressure and operation pressure and pumping energy consumption.



Hydrant-pump discharge and pressure
measurements

24. SEPT. 1980.

MEZŐHÉK-I. Hydrant: 3.3/7

Table 3.8

			Time period /minutes/					
			Unit	15	15	15	15	15
<u>Orifice meter readings</u>								
p	pressure	mm	308	289	243	192	155	
h_{pg}	pressure	mm	34,33	32,77	27,50	22,50	17,50	
Q_h	discharge	l/s	37,47	36,29	33,28	29,59	26,58	
V_h	volume	m^3	33,72	32,66	29,95	26,63	23,92	
H_h	pressure	m	33,56	31,98	26,68	21,64	16,61	
<u>Lateral pressure readings /m/</u>								
Sprinkler	No. 1		22,7	22,4	19,5	15,8	10,5	
	No.12		26,3	25,1	21,2	16,2	13,2	
	No.24		23,0	20,7	17,0	14,0	10,7	
	No.13		25,4	24,1	20,0	15,3	11,4	
<u>Pump operation readings</u>								
Q_p	discharge	l/s	87,70	80,44	77,41	77,63	76,00	
V_p	volume	m^3	78,93	72,40	69,67	69,87	68,40	
H^p	pressure	m	80,67	81,17	82,90	84,00	82,90	
W	electricity	kWh	22,00	25,33	29,33	33,33	36,00	
w	specific energy	kWh/ m^3	0,29	0,35	0,42	0,48	0,53	

During the experiment period the pumped water quantity was shared by an another similar lateral operating on the same main. It is seen from Table 3.8 that when the hydrant valve was fully opened the hydrant discharge was 37,47 l/s at 33,56 m pressure, the corresponding values of discharge rate and operating pressure for pumping center were 87,70 l/s and 80,67 m, respectively.

At this situation pumps operate at their optimum performance. But in case when hydrant valve is throttled in order to get reduced discharge rate - as it is practised many times - pumping consumes increased amount of energy. The specific energy consumption may be as much as 20 to 88 percent higher in case of throttled operation than that of fully opened hydrant operation. Also, it is to note that beyond certain limit of throttling, the lateral water pressure is not sufficient to operate the sprinklers at desired pressure. It was also observed, that there were considerable water leakages at the lateral pipe-joints and at sprinkler connections, with leakages increasing as the hydrant pressure decreases. There were also significant pressure losses in the hose pipes connecting hydrant to the laterals.

4. SIMULATION MODELS FOR OPTIMIZATION OF ENERGY USE IN IRRIGATION

Experience gained from the field experiments, data collection and, review of literature provided an insight for presentation of some reasonable hypothesis dealing with the possibilities of reducing energy demand and energy cost of irrigation. While formulating the hypothesis it was assumed that:

- the pumped irrigation demands the largest share in the total energy requirement for irrigation;
- sprinkler irrigation will continue to be the dominant method of irrigation and, more and more concentrated pumping units on increasingly larger areas will be planned;
- the availability and price of commercial energy sources especially, diesel oil and electricity will be the limiting factor in pumped irrigation development;
- energy prices will have escalating tendency in future too.

Taking these assumptions as the basic considerations, I have presented the following three simulation models dealing with the energy demand and cost of energy in irrigation:

Model No.1. Calculation of pumping energy demand and energy cost of irrigation,

Model No.2. Determination of optimal diameter of irrigation pipelines,

Model No.3. Determination of optimal size of irrigation units.

In all the three models firstly, mathematical relations were developed and the further analysis was made with the help of ODRA-1204 computer. The programmes were written in FORTRAN IV language and an unified system of symbols for input and output parameters was used /Appendix 4.1/.

4.1 The Model No.1.: Calculation of pumping energy demand and energy cost of irrigation

Pumping energy demand depends upon several factors such as, method of irrigation, water source, irrigated area, pumping situations, crops grown and cropping pattern, etc. while, energy cost is influenced by type of energy source, operation periods, energy prices or tariff system. Each factor further involves number of variable parameters thus necessitating the use of computer. The chief objectives of computer programming are as follows;

- to find out the primary and total pumping energy for irrigation.
- 

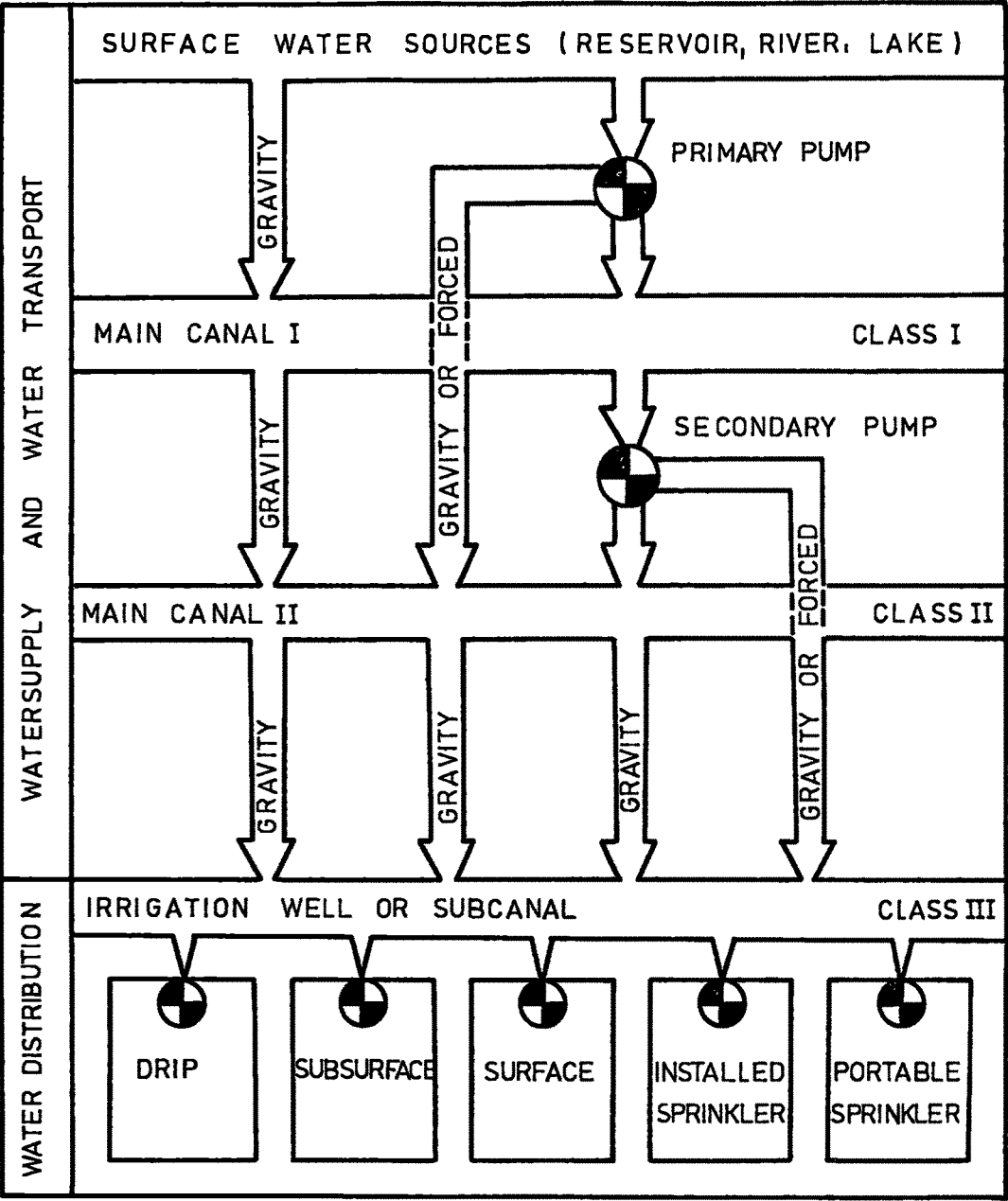


Fig 41 Schematic diagram of possible flow of irrigation water to application

- surface water sources:

1. By gravity
2. By primary lifting
3. By secondary lifting
4. By two stage lifting

- underground water sources:

5. From irrigation well

The methods of irrigation examined in this study are:

1. Portable sprinkler
2. Installed sprinkler
3. Surface /gated pipe/
4. Subsurface /perforated pipe/
5. Drip irrigation

4.1.2 Mathematical relations for computer calculations

The Required Water Discharge /RWD/ of irrigation pumps in liter/sec /L/S/, for a given irrigated area can be calculated by following equation:

$$RWD = \frac{2,78 \cdot IRA \cdot DWA}{IRP \cdot DOH} \quad [L/S] \quad /4.1/$$

where: IRA - total irrigated area /HA/
DWA - depth of water application /MM/
IRP - irrigation period /DAYS/
DOH - daily operation hours /HRS/

The Pump Power Demand /PPD/ for pumping water measured in kilowatt /KW/ on the shaft of pump:

$$PPD = \frac{RWD \cdot TDH}{102 \cdot PEF1} \quad [KW] \quad /4.2/$$

where: TDH - total dynamic head /M/
PEF1- irrigation pump efficiency at given TDH and
RWD /PERC/

4.1.2.1 Electrically operated pumps

The Specific Electric energy Requirement /SER/ for pumping of one cubicmeter of water:

$$SER = \frac{TDH}{367,2 \cdot PEF1 \cdot MEF} \quad [KWH/CUM] \quad /4.3a/$$

or

$$SER = \frac{TDH}{367,2 \cdot PUE1} \quad [KWH/CUM] \quad /4.3b/$$

where: MEF - motor efficiency factor at a given loading of motor /PERC/

PUE1- irrigation pumping unit efficiency /motor and pump together/ /PERC/

The specific yearly Electric Energy Demand /EED/ for irrigating one hectar of land:

$$EED = \frac{SER \cdot NWR}{IEF} \quad [KWH/HA] \quad /4.4/$$

where: NWR - net water requirement /CUM/HA/

IEF - irrigation efficiency /PERC/

The specific yearly Electric Energy Cost /EEC/ of irrigation /FT/HA/ according to the present tariff system in Hungary depends on Pumps Power Demand /PPD/ during Day /PPDD/ and Peak period /PPDP/ and, upon the Electric Energy Demand /EED/ during day and night periods expressed by the Ratio of Night Tariff /RNT/, as follows:

$$EEC = \frac{A \cdot PPDD + B \cdot PPDP}{IRA} + EED \cdot [C - RNT \cdot /C-D/] \quad [FT/HA] \quad /4.5/$$

where: PPDD - electric power demand, day period /KW/
 PPDP - electric power demand, peak period /KW/
 EED - electric energy demand in a year /KWH/HA/
 RNT - ratio of night tariff
 A,B,C,D - tariff constants as follows:

A - cost of power during day period /Ft/KW/
 B - cost of power during peak period /FT/KW/
 C - cost of energy during day period /FT/KWH/
 D - cost of energy during night period /FT/KWH/

The Specific Electric energy Cost /SEC/ related to the unit of water applied over the field:

$$SEC = \frac{EEC \cdot IEF}{NWR} \quad [FT/CUM] \quad /4.6/$$

The specific yearly Electrical energy Demand for Lifting /EDL/ water during conveying can be determined as follows:

$$EDL = \frac{THL \cdot NWR}{367,2 \cdot PEF2 \cdot MEF \cdot IEF \cdot TEF} \quad [KWH/HA] \quad /4.7a/$$

or,

$$EDL = \frac{THL \cdot NWR}{367,2 \cdot PUE2 \cdot IEF \cdot TEF} \quad [KWH/HA] \quad /4.7b/$$

where: THL - total head of lifting /M/
 PUE2- pumping unit efficiency of lift pump /PERC/
 TEF - transport efficiency factor /PERC/

TEF depends on type of water transport i.e. through pipeline or open canal and thus the extent of water losses during conveying.

The specific Electric energy Cost of Lifting /ECL/ water:

$$ECL = EDL \cdot E \quad [FT/HA] \quad /4.8/$$

where: E - average price of electricity /FT/KWH/

The Total Electric energy Demand /TED/ of irrigation water application and water lifting therefore is:

$$TED = EED + EDL \quad [KWH/HA] \quad /4.9/$$

and the Total Electric energy Cost /TEC/ is:

$$TEC = EEC + ECL \quad [FT/HA] \quad /4.10/$$

4.1.2.2 Diesel operated irrigation pumps

The Specific Diesel oil Requirement /SDR/ for pumping one cubicmeter of water is calculated as follows:

$$SDR = \frac{TDH \cdot SFC}{367,2 \cdot \eta_{eff}} \quad [KG/CUM] \quad /4.11/$$

where: SFC - specific fuel consumption /KG/KWH/

The specific yearly Diesel oil Energy Demand /DED/ for irrigating one hectar of land in /KG/HA/:

$$DED = \frac{SDR \cdot NWR}{IEF} \quad [KG/HA] \quad /4.12/$$

The specific yearly Diesel oil Energy Cost /DEC/ of irrigation /FT/HA/ depends only upon the average national diesel oil price:

$$DEC = DED \cdot P \quad [FT/HA] \quad /4.13/$$

where: P- diesel oil price /FT/KG/

The Specific Diesel oil energy Cost /SDC/ related to the unit of water pumped:

$$SDC = \frac{DEC \cdot IEF}{NWR} \quad [FT/CUM] \quad /4.14/$$

The specific yearly Diesel oil energy Demand for Lifting /DDL/ water during conveying:

$$DDL = \frac{THL \cdot NWR \cdot SFC}{367,2 \cdot PEF2 \cdot IEF \cdot TEF} \quad [KG/HA] \quad /4.15/$$

and the specific Diesel oil energy Cost for Lifting /DCL/ water:

$$DCL = DDL \cdot P \quad [FT/HA] \quad /4.16/$$

The Total Diesel oil energy Demand of irrigation and water supply application and water lifting /TDD/ therefore is:

$$TDD = DED + DDL \quad [KG/HA] \quad /4.17/$$

and the Total Diesel oil Cost /TDC/ is:

$$TDC = DEC + DCL \quad [FT/HA] \quad /4.18/$$

The flow diagram using the mathematical relations from /4.1/ to /4.18/ for computer operation is shown in Fig.4.2.

4.1.3 Input paramters for Model No.1.

The input parameters required for computerizing Model No.1. are:

IRA	NWR	PUE2	PPDP	C
IRP	PEF1	TEF	P	RNT
DWA	IEF	THL	E	D
DOH	PEF2	SFC	A	
TDH	PUE1	PPDD	B	

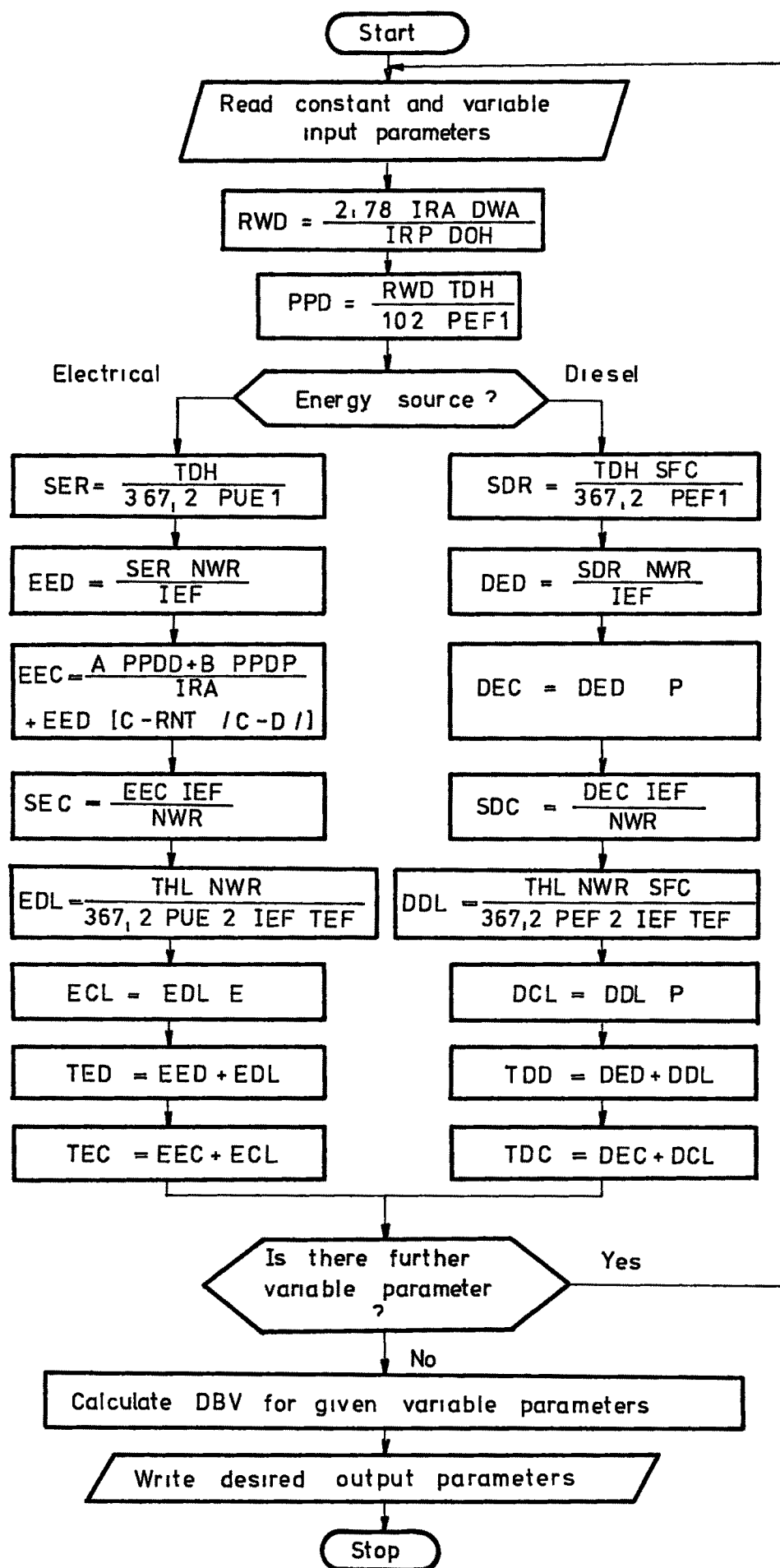


Fig 4 2 Flow diagram for Computer program of Model No 1

The base values of input parameters which are characteristic for the given irrigation method under average operating conditions are given in Appendix 4.2. The computer programme for Modell No.1. prepared by Nándor KOMÁROMI assistant at Computer Centre of University of Agricultural Sciences, Godolló is presented in Appendix 4.3.

4.1.4 Model outputs and interpretation

For the given energy source and irrigation method, the base data form Appx. 4.2 is supplied for one run of computer which prints out the values of output parameters in tabular form, as e.g. Table 4.1 and 4.2 which includes:

RWD	EEC	TED	DEC	TDD
PPD	SEC	TDC	SDC	TDC
SER	EDL	SDR	DDL	DBV
EED	ECL	DED	DCL	

The specific energy and energy cost requirement values for electrically and diesel operated pumping units for different irrigation methods and various water sources are presented in detail in Appendix 4.4 and summarized in Table 4.3.

It can be seen from Table 4.3 that if the irrigation water is transported to the field by one or more than one pumping stages then the energy content of the water considerably increases. The energy required for water transport in case of high head systems i.e. sprinkler may be 10 to 30 per cent and in case of low head systems i.e. surface, subsurface and drip, may be 60 to 200 per cent of that required for actual water application. The total energy requirement of irrigation is thus, the addition of primary pumping energy and water application energy.

An irrigation system operating at low-pressure, high pumping unit efficiency and applying water at higher efficiency, has low specific energy consumption. Thus by using the specific energy

Table 4.1

Results of computer programming for Model No.1

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

ELFCTRICALLY OPERATED PUMPS
SURFACE WATER SOURCES BY GRAVITY
INSTALLED SPRINKLER IRRIGATION

IRA= 1200 HA PUE1= 60.0 PERC B = 750.0 FT/KW
DWA= 60.0 MM PUE2= 0.0 PERC C = 1.3 FT/KWH
IRP= 18.0 DAYS THL= 0.0 M D = 0.7 FT/KWH
DOH= 18.0 HRS TEF= 0.0 PERC RNT = 0.0 PERC
TDH= 75.0 M SFC= 0.0 KG/KWH
NWR= 1260 CUM/HA PPOP= 0.0 KW
IEF= 70.0 PERC E = 1.6 FT/KWH
PEF1= 75 PERC P = 0.0 FT/KG
PEF2= 0. PERC A = 270.0 FT/KW

IRP DAYS	PPD KW	SFR KWH/CUM	EED KWH/HA	EEC FT/HA	SEC FT/CUM	EDL KWH/HA	ECL FT/HA	TED KWH/HA	TLC FT/HA	DBV FT/HA
10 00	1039 32	0 34	612 75	1041 67	0 58	0 00	0 00	612 75	1041 67	0 00
12 00	917 77	0 34	612 75	1000 82	0 56	0 00	0 00	612 75	1000 82	0 00
14 00	778 09	0 34	612 75	971 64	0 54	0 00	0 00	612 75	971 64	0 00
16 00	680 83	0 34	612 75	949 75	0 53	0 00	0 00	612 75	949 75	0 00
18 00	605 18	0 34	612 75	932 73	0 52	0 00	0 00	612 75	932 73	0 00
20 00	544 66	0 34	612 75	919 12	0 51	0 00	0 00	612 75	919 12	0 00
22 00	495 15	0 34	612 75	907 98	0 50	0 00	0 00	612 75	907 98	0 00
24 00	453 89	0 34	612 75	898 69	0 50	0 00	0 00	612 75	898 69	0 00
26 00	418 97	0 34	612 75	890 84	0 49	0 00	0 00	612 75	890 84	0 00

DOH HOURS	PPD KW	SER KWH/CUM	EED KWH/HA	FFC FT/HA	SEC FT/CUM	EDL KWH/HA	ECL FT/HA	TED KWH/HA	TFC FT/HA	DBV FT/HA
8 00	1351 66	0 54	612 75	1102 94	0 61	0 00	0 00	612 75	1102 94	0 00
10 00	1019 32	0 34	612 75	1041 67	0 58	0 00	0 00	612 75	1041 67	0 00
12 00	907 77	0 34	612 75	1000 82	0 56	0 00	0 00	612 75	1000 82	0 00
14 00	778 09	0 34	612 75	971 64	0 54	0 00	0 00	612 75	971 64	0 00
16 00	680 83	0 34	612 75	949 75	0 53	0 00	0 00	612 75	949 75	0 00
18 00	605 18	0 34	612 75	932 73	0 52	0 00	0 00	612 75	932 73	0 00
20 00	544 66	0 34	612 75	919 12	0 51	0 00	0 00	612 75	919 12	0 00
22 00	495 15	0 34	612 75	907 98	0 50	0 00	0 00	612 75	907 98	0 00

Table 4.2

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

ELCTRICALLY OPERATED PUMPS
SURFACE WATER SOURCES BY GRAVITY
INSTALLED SPRINKLER IRRIGATION

IRA= 1200 HA
DWA= 60 0 MM
IRP= 18 0 DAYS
DUH= 18 0 HRS
TDH= 75 0 M
NWR= 1200 CUM/HA
IEF= 70 0 PERC
PEF1= 75 UPERC
PEF2= 100 UPERC

PUE1= 60 0 PERC
PUE2= 100 0 PERC
THL= 0 0 M
TEF= 100 0 PERC
SFC= 0 0 KG/KWH
PPDP= 0 0 KW
F= 1 6 FT/KWH
P= 0 0 FT/KG
A= 270 0 FT/KW

B= 750 0 FT/KW
C= 1 3 FT/KWH
D= 0 7 FT/KWH
RNT= 0 0 PPERC

TDH M	PPD		SER		EED		EEC		SEC		EDL		ECL		TED		TEC		DBV	
	KW	PPD	KWH/CUM	KWH/HA	KWH/HA	FT/HA	FT/HA	FT/CUM	KWH/HA	KWH/HA	FT/HA	FT/HA	FT/HA	FT/HA	KWH/HA	KWH/HA	FT/HA	FT/HA	FT/HA	FT/HA
65 00	574 49		0 30	531 05	808 37	0 45	0 00	0 00	531 05	808 37	0 00	0 00	0 00	531 05	808 37	0 00	0 00	808 37	-81 70	-124 36
67 00	540 63		0 30	547 39	833 24	0 46	0 00	0 00	547 39	833 24	0 00	0 00	0 00	547 39	833 24	0 00	0 00	833 24	-65 36	-99 49
67 00	556 77		0 31	563 73	858 12	0 48	0 00	0 00	563 73	858 12	0 00	0 00	0 00	563 73	858 12	0 00	0 00	858 12	-49 02	-74 62
71 00	572 90		0 32	580 07	882 99	0 49	0 00	0 00	580 07	882 99	0 00	0 00	0 00	580 07	882 99	0 00	0 00	882 99	-32 68	-49 75
73 00	589 04		0 33	596 41	907 86	0 50	0 00	0 00	596 41	907 86	0 00	0 00	0 00	596 41	907 86	0 00	0 00	907 86	-16 34	-24 87
75 00	605 18		0 34	612 75	932 73	0 52	0 00	0 00	612 75	932 73	0 00	0 00	0 00	612 75	932 73	0 00	0 00	932 73	0 00	0 00
77 00	621 32		0 35	629 08	957 61	0 53	0 00	0 00	629 08	957 61	0 00	0 00	0 00	629 08	957 61	0 00	0 00	957 61	16 34	24 87
79 00	637 46		0 36	645 42	982 48	0 55	0 00	0 00	645 42	982 48	0 00	0 00	0 00	645 42	982 48	0 00	0 00	982 48	32 68	49 75
81 00	653 59		0 37	661 76	1007 35	0 56	0 00	0 00	661 76	1007 35	0 00	0 00	0 00	661 76	1007 35	0 00	0 00	1007 35	49 02	74 62
83 00	669 73		0 38	678 10	1032 23	0 57	0 00	0 00	678 10	1032 23	0 00	0 00	0 00	678 10	1032 23	0 00	0 00	1032 23	65 36	99 49
85 00	685 87		0 39	694 44	1057 10	0 59	0 00	0 00	694 44	1057 10	0 00	0 00	0 00	694 44	1057 10	0 00	0 00	1057 10	81 70	124 36
87 00	702 01		0 39	710 78	1081 97	0 60	0 00	0 00	710 78	1081 97	0 00	0 00	0 00	710 78	1081 97	0 00	0 00	1081 97	98 04	149 24
87 00	718 15		0 40	727 12	1106 84	0 61	0 00	0 00	727 12	1106 84	0 00	0 00	0 00	727 12	1106 84	0 00	0 00	1106 84	114 38	174 11
91 00	734 29		0 41	743 46	1131 72	0 63	0 00	0 00	743 46	1131 72	0 00	0 00	0 00	743 46	1131 72	0 00	0 00	1131 72	130 72	198 98
93 00	750 42		0 42	759 80	1156 59	0 64	0 00	0 00	759 80	1156 59	0 00	0 00	0 00	759 80	1156 59	0 00	0 00	1156 59	147 06	223 86
95 00	766 56		0 43	776 14	1181 46	0 66	0 00	0 00	776 14	1181 46	0 00	0 00	0 00	776 14	1181 46	0 00	0 00	1181 46	163 40	248 73

NJR CUM/HA	PPD		SER		EED		EEC		SEC		EDL		FCL		TED		TEC		DBV	
	KW	PPD	KWH/CUM	KWH/HA	KWH/HA	FT/HA	FT/HA	FT/CUM	KWH/HA	KWH/HA	FT/HA	FT/HA	FT/HA	FT/HA	KWH/HA	KWH/HA	FT/HA	FT/HA	FT/HA	FT/HA
420 00	605 18		0 34	204 25	401 69	0 67	0 00	0 00	204 25	401 69	0 00	0 00	0 00	204 25	401 69	0 00	0 00	401 69	-408 50	-531 05
630 00	605 14		0 34	306 37	534 45	0 59	0 00	0 00	306 37	534 45	0 00	0 00	0 00	306 37	534 45	0 00	0 00	534 45	-306 37	-398 28
840 00	605 18		0 34	408 50	667 21	0 56	0 00	0 00	408 50	667 21	0 00	0 00	0 00	408 50	667 21	0 00	0 00	667 21	-204 25	-265 52
1050 00	605 18		0 34	510 62	799 97	0 53	0 00	0 00	510 62	799 97	0 00	0 00	0 00	510 62	799 97	0 00	0 00	799 97	-102 12	-132 76
1260 00	605 18		0 34	612 75	932 73	0 52	0 00	0 00	612 75	932 73	0 00	0 00	0 00	612 75	932 73	0 00	0 00	932 73	0 00	0 00
1470 00	605 18		0 34	714 87	1065 50	0 51	0 00	0 00	714 87	1065 50	0 00	0 00	0 00	714 87	1065 50	0 00	0 00	1065 50	102 12	132 76
1680 00	605 18		0 34	816 99	1198 26	0 50	0 00	0 00	816 99	1198 26	0 00	0 00	0 00	816 99	1198 26	0 00	0 00	1198 26	204 25	265 52
1890 00	605 18		0 34	919 12	1331 02	0 49	0 00	0 00	919 12	1331 02	0 00	0 00	0 00	919 12	1331 02	0 00	0 00	1331 02	306 37	398 28
2100 00	605 18		0 34	1021 24	1463 78	0 49	0 00	0 00	1021 24	1463 78	0 00	0 00	0 00	1021 24	1463 78	0 00	0 00	1463 78	408 50	531 05

Table 4.3

Pumping energy demand and cost of different irrigation methods^x

1. Electrically operated pumps

Irrigation method	Surface water source by						Underground water source	
	gravity		primary lifting		secondary lifting		twostage lifting	
	kWh/ha	Ft/ha	kWh/ha	Ft/ha	kWh/ha	Ft/ha	kWh/ha	Ft/ha
Portable sprinkler	659,88	1004,48	741,58	1135,20	753,25	1146,16	850,51	1309,49
Installed sprinkler	612,75	932,73	694,44	1063,45	706,12	1082,13	803,38	1237,75
Surface irrigation	102,12	161,94	197,44	314,45	211,06	336,23	324,53	517,79
Subsurface	114,89	173,67	186,38	288,05	196,59	304,39	281,69	440,56
Drip irrigation	65,65	111,61	106,50	176,97	112,34	186,30	160,97	264,11
							117,84	196,95

2. Diesel operated pumps

	kg/ha	Ft/ha	kg/ha	Ft/ha	kg/ha	Ft/ha	kg/ha	Ft/ha
Portable sprinkler	158,37	1583,71	179,97	1799,68	183,05	1830,53	208,76	2087,63
Installed sprinkler	147,06	1470,59	168,66	1686,55	171,74	1717,41	197,45	1974,51
Surface irrigation	24,51	245,10	49,71	497,06	53,31	533,05	83,30	833,00
Subsurface	27,57	275,74	46,47	464,71	49,17	491,70	71,67	716,60
Drip irrigation	15,76	157,56	26,26	262,64	28,10	280,97	40,95	409,52
							30,64	306,37

x For the base data from Appendix 4.2

demand values from Table 4.3 the energy demand descending order of irrigation systems is: portable sprinkler, installed sprinkler, subsurface, surface and drip.

The specific energy cost figures from the Table 4.3 indicate that for the present energy pricing system, operating energy cost of the diesel pumps is 40 to 60 percent higher than electrically operated pumps. This is on the one hand due to low efficiency of diesel engine in converting diesel oil energy content to useful power, and also due to the basic characteristic difference in pricing of the electricity and diesel oil on the other.

The selection of input parameters during designing of a given irrigation system has an effect on pumping capacity i.e. on the total installed power /KW/, which in turn significantly influences the specific energy cost of irrigation. Although the specific energy requirement for applying given amount of water remains unchanged. The model enables to vary a desired input parameter within the reasonable range to know its effect on energy demand and energy cost requirement. Appendix 4.4 presents the results of the computer calculations by varying some of the base parameters. The base data related to given energy source, water source, and irrigation method are printed out at the top of the tables. The first column of each table is the variable parameter which is modified within suitable range to know its effect on energy savings or extra energy requirement.

Fig. 4.3 can be used to calculate the percentage energy saving or extra requirement resulting from simultaneous modification of TDH, DWA, NWR, IEF, PEF1, PUE1, and SFC, in case of sprinkler irrigation.

It can be observed that the highest possibility of reducing energy demand lies in modifying the pressure head requirement i.e. TDH, and pumping unit efficiency /PUE/ in case of sprinkler system, while improving the irrigation efficiency

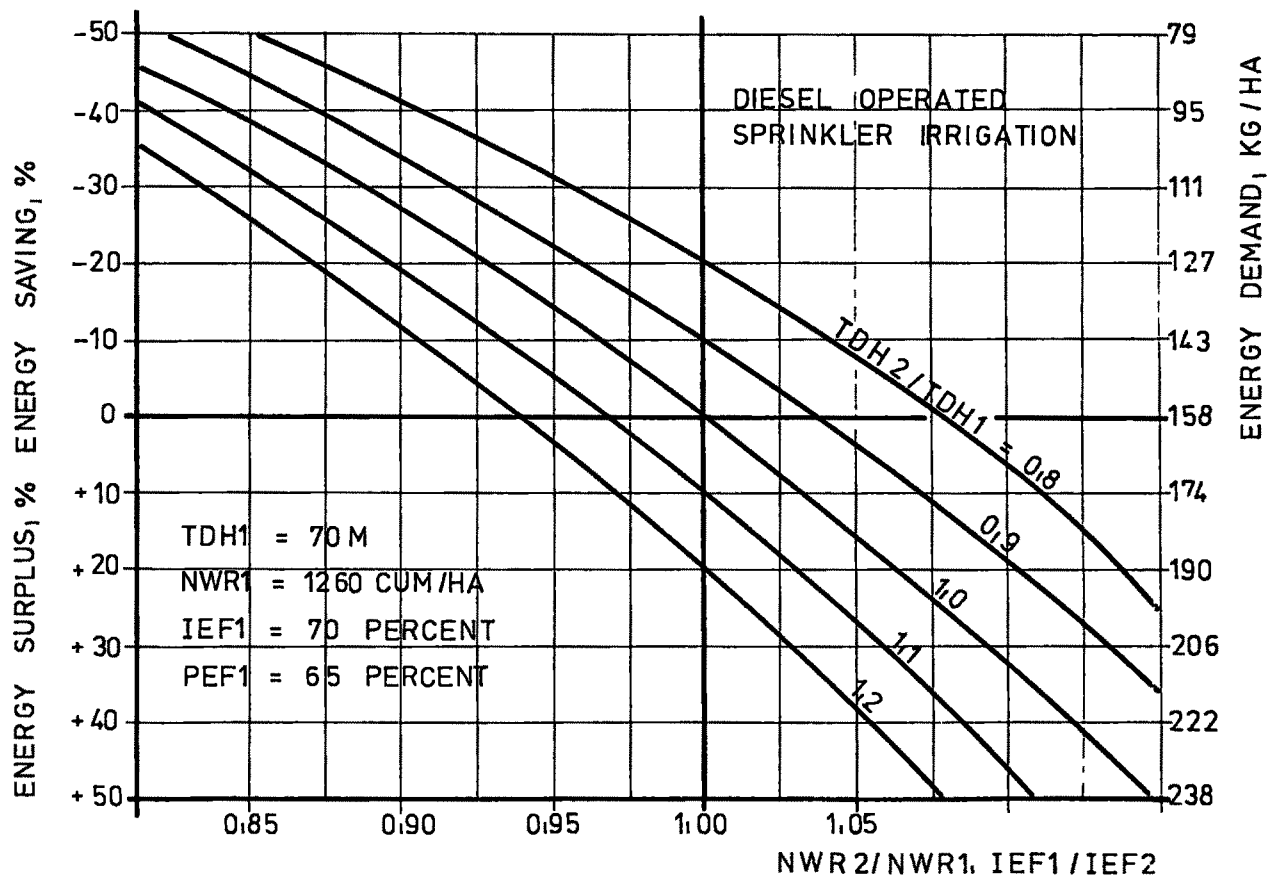
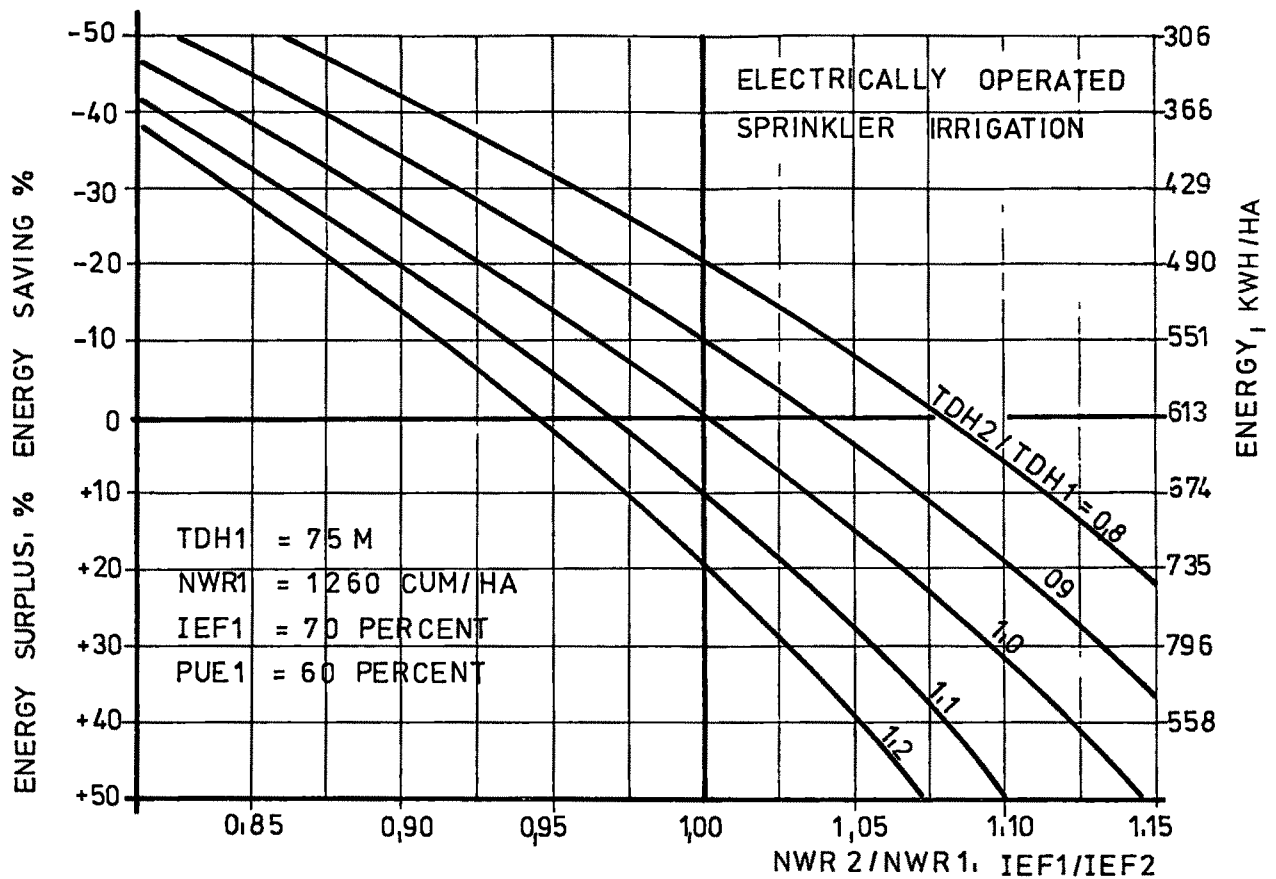


Fig 4.3 Saving or surplus of energy demand resulted from changing NWR, IEF or PUE

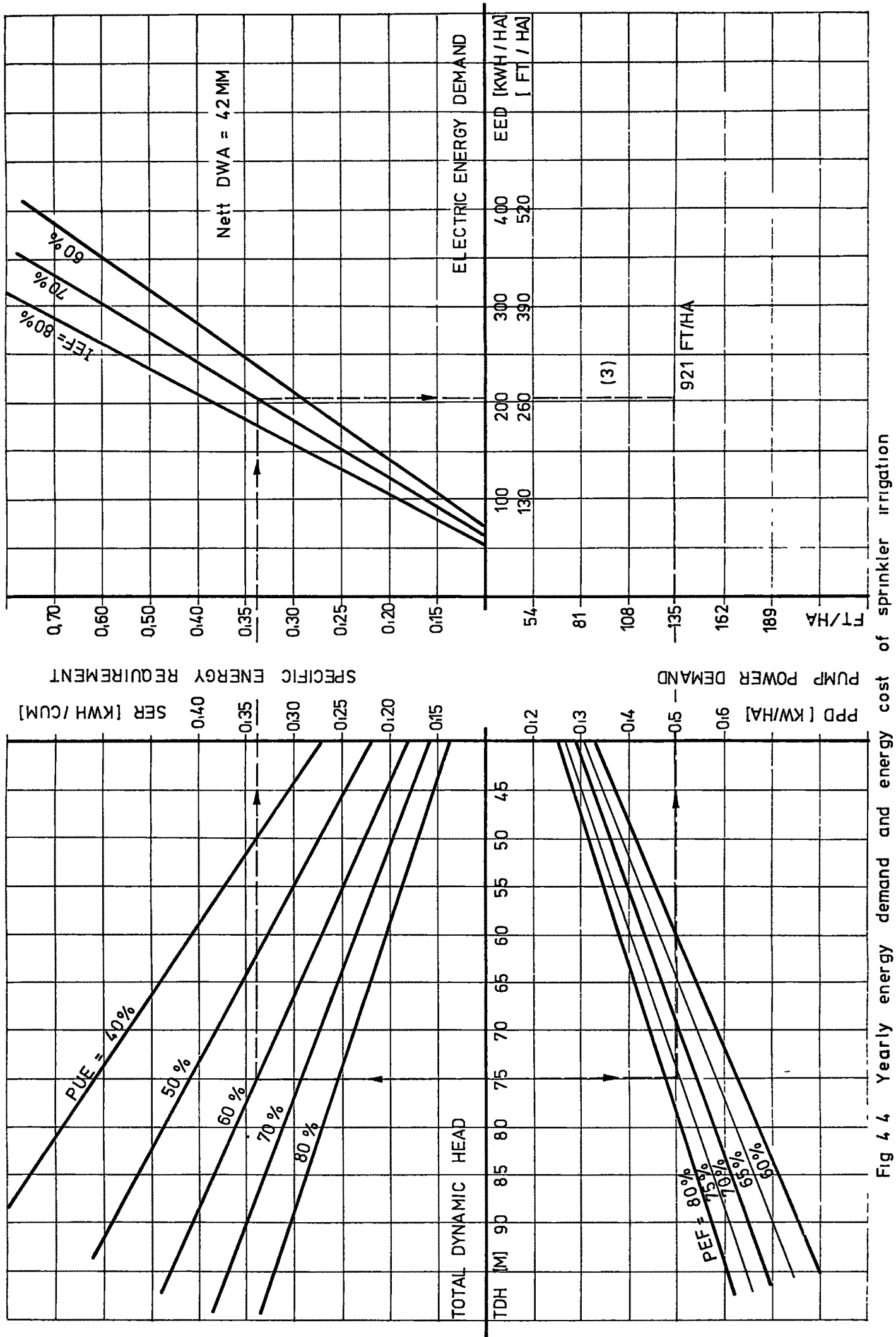


Fig 4 4 Yearly energy demand and energy cost of sprinkler irrigation

/IEF/ will further reduce the energy demand of surface system.

Fig. 4.4 can be used for calculating specific pumping energy demand and energy cost of applying 42 mm of net irrigation water by sprinkler method for various total heads, pump and pumping unit efficiencies, and irrigation efficiencies. The specific energy demand value should be multiplied with number of water applications before adding to the yearly specific power cost to get the yearly total energy cost per hectare.

4.2 The Model No.2.: Determination of optimal diameter of irrigation pipelines

In modern irrigation systems, especially in sprinkler system pipes are indispensable component. The pipes may be used as main, submain, and lateral. The pipe size generally required in sprinkler irrigation ranges from 0,08 M to 0,70 M, having operating pressure range between 0,4 MPa to 1,0 MPa. The commonly used materials for irrigation pipes are asbestos cement, PVC, aluminium, and steel.

The pumping energy demand is directly related with the hydraulic energy required for water transport through pipe network. Whereas, the hydraulic energy depends on the friction losses occurring in the pipes. It is well known that by increasing of pipe diameter its investment cost increases, but simultaneously the friction losses i.e. the energy requirement of water transport decreases. In general, the selection of optimum pipe size consists of finding out that diameter of pipe section which has minimum annual sum of fixed and operating cost, for the given operating conditions. However, during optimization the designer considers the current energy prices and did not take in to account the expected price rise over the life of a pipe installation. Here, the computer model has been developed for determination of optimal pipe diameter of irrigation pipe sections with the assumption that the energy price will have escalating trend in future too.

4.2.1 The objective of computer programming

The selection of optimal diameter of irrigation pipeline is influenced by various parameters which are:

PDM - available Pipe Diameters /M/
PFF - Pipe Friction Factor
PWD - Pipe Water Discharge /CUM/S/
EPD - Electric Power Demand of pump /KW/
YOH - Yearly Operation Hours /HRS/
E - average price of electricity /FT/KWH/
SPC - Specific Pipe Cost /FT/M/

The main objective of computer model is to find out the optimal diameter /DMP^x/ of pipeline for several input parameters, based on minimum energy cost requirement.

4.2.2 Mathematical relations for computer programming

The Pipe section Water Velocity /PWV/:

$$PWV = \frac{1,27 \cdot PWD}{PDM^2} \quad [M/S] \quad /4.19/$$

Which should be:

$$0,5 \leq PWV \leq 2,5 \text{ M/S}$$

The Specific Head Loss /SHL/ for a given pipeline can be calculated by the Hazen-Williams formula:

$$SHL = 0,0021 \cdot PFF \cdot PWD^{1,85} \cdot PDM^{-4,86} [M/M] \quad /4.20/$$

The values of Pipe Friction Factor /PFF/ used for design purposes are as follows:

for asbestos cement : 0,70 and for PVC : 0,55

The Electric Power Demand /EPD/:

$$EPD = \frac{1000 \cdot PWD \cdot SHL}{102 \cdot PEF \cdot MEF} \quad [KW] \quad /4.21a/$$

or,

$$EPD = \frac{9,804 \cdot PWD \cdot SHL}{PUE} \quad [KW] \quad /4.21b/$$

where: PEF - pump efficiency factor /PERC/
 MEF - motor efficiency factor /PERC/
 PUE - pumping unit efficiency /PERC/

The Yearly Electric energy Demand /YED/:

$$YED = EPD \cdot YOH \quad [KWH] \quad /4.22/$$

The Yearly Electric energy Cost /YEC/:

$$YEC = YED \cdot E \quad [FT] \quad /4.23/$$

The Yearly Pipe-section Cost is determined as follows:

$$YPC = CRF \cdot SPC \quad [FT/M] \quad /4.24/$$

where: CRF - capital recovery factor, and is calculated from following formula:

$$CRF = \frac{I [1 + I]^N}{[1 + I]^N - 1} \quad /4.25/$$

where: I - the interest rate /PERC/
 N - the life of the installation /YEAR/

Thus the Yearly Total Cost /YTC/ of operation of pipe-section i.e. water transport, excluding the permanent components is:

$$YTC = YEC + YPC \quad [FT] \quad /4.26/$$

The flow diagram for computer operation is shown in Fig. 4.5. The model determines the minimal value of YTC for all the different possible variations of pipe materials, diameters, water

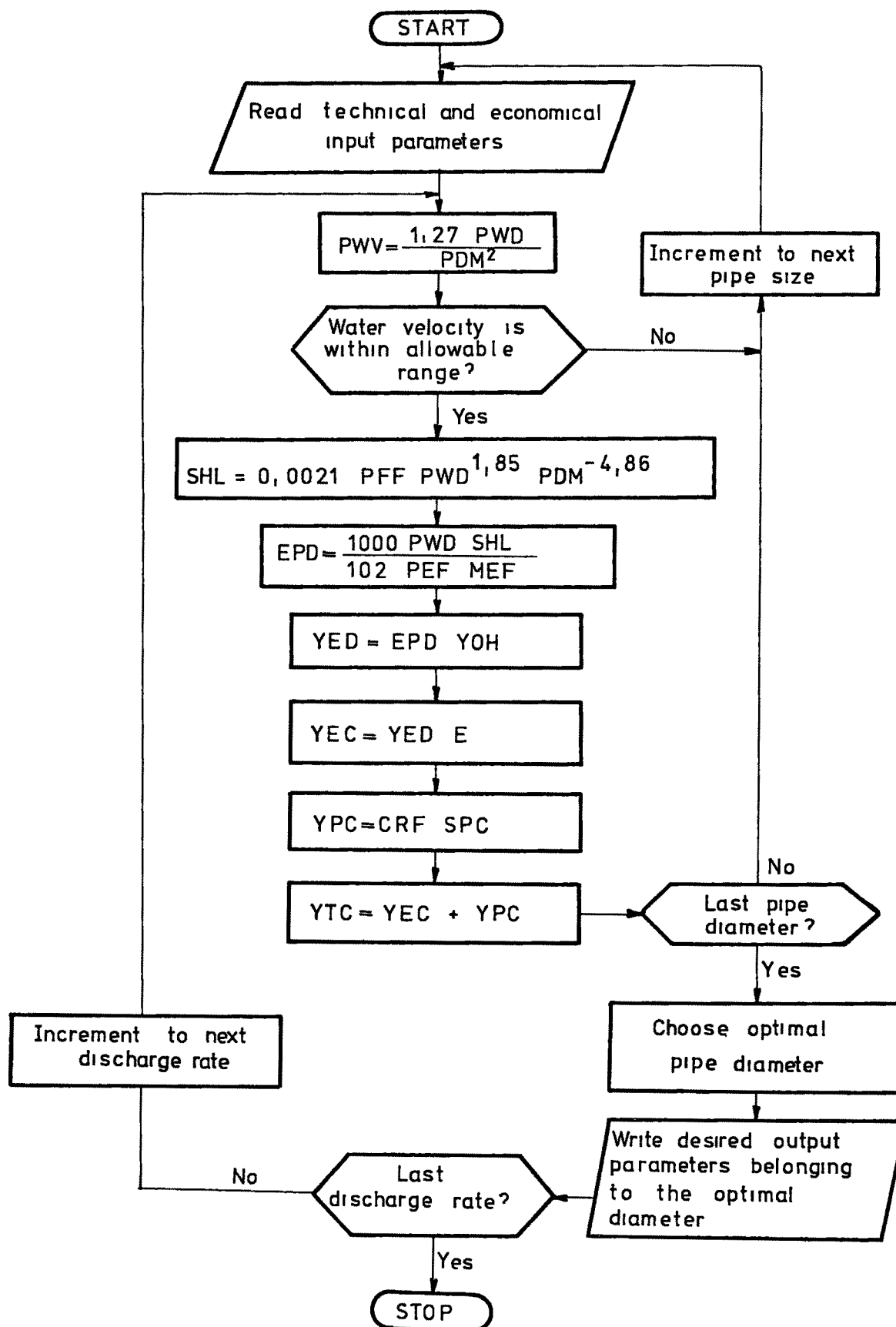


Fig 4 5 Flow diagram for Computer program of Model No 2

discharges, yearly operation hours, etc. in case of several average electricity prices, and prints out the values of different parameters belonging to the optimal solutions.

4.2.3 The model inputs

For the sake of calculation, values of the standard diameters of pipe along with their specific prices are given in Appendix 4.5. The Required Water Discharge taken into consideration starts from 0,05 CUM/S and lasts up to 0,5 CUM/S by 0,05 CUM/S increment. Both Pump Efficiency Factor and Motor Efficiency Factor are fixed up in this analysis as 70 and 80 percent, respectively i.e. the Pumping Unit Efficiency as 56 percent. The Yearly Operation Hours changes from 500 hours up to 2500 hours by 500 hours increment. The average prices of electricity are arbitrarily chosen and, change between the limits of 0,30 FT/KWH and 6,00 FT/KWH by 0,30 FT/KWH increment. The Capital Recovery Factor values for six different life cycles and for four different rates of interest calculated by the formula /4.25/ are presented in table of Appendix 4.5. In this analysis the Capital Recovery Factor is taken up as constant factor belonging to 15 years life cycle and 10 percent of interest i.e. as 0,132. The computer programme for Modell No.2 prepared by Nándor KOMÁROMI, assistant at Computer Centre of University of Agricultural Sciences, Godolló, is presented in Appendix 4.6.

4.2.4 The model outputs and interpretation

For the present analysis, as an example, the individual computer runs for only one material i.e. for asbestos cement pipes were carried out, for all the variations of:

- the 10 different water discharges,
- the 5 different yearly operation hours, and
- the 20 different average energy prices.

In each iteration the model prints out:

- the values of optimum pipe diameters $/PDM^x/$, belonging to the given pipe material, yearly operation hours, water discharges and energy prices;
- the specific headloss $/SHL/$, yearly electric energy demand $/YED/$, and yearly total cost $/YTC/$ of operating the pipe section, belonging to the optimum value of pipe diameter $/PDM^x/$.

The model, firstly selects the most economical pipe-section size from among the hydraulically suitable pipe sizes, for a given average price of energy, and then prints out this pipe diameter value before the respective energy prices arranged in the ascending order.

The results of the computer calculations are presented in Appendix 4.7 and as an example in Table 4.4, showing the effect of escalating energy prices on the selection of pipe sizes at given discharge rates and annual operating hours.

For example in case of $YOH=1000$ HRS /Table 4.4/ for carrying out $0,05$ CUM/S of water flow rate, the $0,20$ M pipe size is the most economical one, but as the electricity price increases to $1,80$ FT/KWH then the $0,25$ M diameter size becomes most economical. In the case of $0,40$ CUM/S, there are three optimum pipe sizes within the selected range of energy prices. For $YOH=2000$ HRS /Appendix 4.7/, for the same discharge rates, the optimum values of pipe diameter significantly changes. For example in case of $0,35$ CUM/S flow rate, at the average energy price between $0,30$ and $1,20$ FT/KWH the $0,50$ M, between $1,5$ and $3,6$ FT/KWH the $0,70$ M pipe size are the optimum ones. It is interesting to note that in case of $0,50$ CUM/S discharge rate, there is no significant effect of escalating energy prices /for the assumed range/ on the selection of optimum pipe size. The shift over to $0,60$ M pipe size is due to increase in yearly operating hours i.e. 2000 and 2500 HRS. This is due to lower specific head losses and thus lower energy cost as compared to the yearly specific cost of the related pipe-section.

Table.4.4

THE SPECIFIC HEADLOSS / RELONGING TO OPTIMUM VALUE OF /PDM*/
AND YEARLY TOTAL COST /YTC/

MATERIAL																ASB.CEM.	
YON= 1000HRS																	
0 25 CUM/S																	
0 20 CUM/S																	
0 15 CUM/S																	
0 10 CUM/S																	
0 05 CUM/S																	
0 30 CUM/S																	
0 45 CUM/S																	
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Table. 4.4

THE OPTIMUM VALUE OF IRRIGATION PIPE DIAMETER /PDM*/
YEARLY ENERGY DELAYD /YED/ AND YEARLY ENERGY COST /YEC/

EN PRICE		0.05 CUM/S				0.10 CUM/S				0.15 CUM/S				0.20 CUM/S				0.25 CUM/S			
		PDM*	YED	YEC	PDM*	YED	YEC	PDM*	YED	YEC	PDM*	YED	YEC	PDM*	YED	YEC	PDM*	YED	YEC	PDM*	YED
FT/KWH	M	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH
YUH= 100UHRS																					
0.30	0.20	0.20	12.58	3.77	0.25	50.56	9.20	0.30	40.14	12.04	0.40	22.51	6.75	0.40	42.53	12.76	0.40	42.53	12.76	0.40	42.53
0.60	0.20	0.20	12.58	7.55	0.25	30.56	18.39	0.30	40.14	24.08	0.40	22.51	13.51	0.40	42.53	25.52	0.40	42.53	25.52	0.40	42.53
0.90	0.20	0.20	12.58	11.32	0.25	30.56	27.59	0.30	40.14	36.13	0.40	22.51	20.26	0.40	42.53	38.27	0.40	42.53	38.27	0.40	42.53
1.20	0.20	0.20	12.58	15.09	0.25	30.56	36.79	0.30	40.14	48.17	0.40	22.51	27.02	0.40	42.53	51.03	0.40	42.53	51.03	0.40	42.53
1.50	0.20	0.20	12.58	18.87	0.30	12.54	18.96	0.30	40.14	60.21	0.40	22.51	33.77	0.40	42.53	63.79	0.40	42.53	63.79	0.40	42.53
1.80	0.25	0.25	4.25	7.65	0.30	12.54	22.75	0.30	40.14	72.25	0.40	22.51	40.53	0.40	42.53	76.55	0.40	42.53	76.55	0.40	42.53
2.10	0.25	0.25	4.25	8.33	0.30	12.64	26.54	0.40	9.92	20.83	0.40	22.51	47.28	0.40	42.53	89.30	0.40	42.53	89.30	0.40	42.53
2.40	0.25	0.25	4.25	10.21	0.30	12.64	30.33	0.40	9.92	23.80	0.40	22.51	54.03	0.40	42.53	102.06	0.40	42.53	102.06	0.40	42.53
2.70	0.25	0.25	4.25	11.43	0.30	12.54	34.13	0.40	9.92	26.78	0.40	22.51	60.79	0.50	14.58	58.82	0.50	14.58	58.82	0.50	14.58
3.00	0.25	0.30	4.25	12.76	0.30	12.54	37.92	0.40	9.92	29.75	0.40	22.51	67.54	0.50	14.58	43.13	0.50	14.58	43.13	0.50	14.58
3.30	0.25	0.30	4.25	14.03	0.30	12.54	41.71	0.40	9.92	32.73	0.40	22.51	74.30	0.50	14.58	47.44	0.50	14.58	47.44	0.50	14.58
3.60	0.25	0.30	4.25	15.31	0.30	12.64	45.50	0.40	9.92	35.70	0.40	22.51	81.05	0.50	14.58	51.76	0.50	14.58	51.76	0.50	14.58
3.90	0.25	0.30	4.25	16.58	0.30	12.64	49.29	0.40	9.92	38.68	0.40	22.51	87.80	0.50	14.58	56.07	0.50	14.58	56.07	0.50	14.58
4.20	0.25	0.30	4.25	17.86	0.30	12.64	53.08	0.40	9.92	41.65	0.40	22.51	94.56	0.50	14.58	60.38	0.50	14.58	60.38	0.50	14.58
4.50	0.25	0.30	4.25	19.13	0.30	12.54	56.88	0.40	9.92	44.63	0.40	22.51	101.31	0.50	14.58	64.70	0.50	14.58	64.70	0.50	14.58
4.80	0.25	0.30	4.25	20.41	0.30	12.64	60.67	0.40	9.92	47.60	0.40	22.51	108.07	0.50	14.58	69.01	0.50	14.58	69.01	0.50	14.58
5.10	0.25	0.30	4.25	21.69	0.30	12.54	64.46	0.40	9.92	50.58	0.50	7.61	58.87	0.50	14.58	73.32	0.50	14.58	73.32	0.50	14.58
5.40	0.25	0.30	4.25	22.90	0.30	12.64	68.25	0.40	9.92	53.55	0.50	7.61	41.10	0.50	14.58	77.64	0.50	14.58	77.64	0.50	14.58
5.70	0.25	0.30	4.25	24.24	0.30	12.54	72.04	0.40	9.92	56.53	0.50	7.61	43.39	0.50	14.58	81.95	0.50	14.58	81.95	0.50	14.58
6.00	0.25	0.40	4.25	25.51	0.40	3.12	18.74	0.40	9.92	59.50	0.50	7.61	45.67	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
0.30 CUM/S																					
0.30	0.50	0.50	37.51	11.25	0.50	54.88	16.46	0.50	76.77	23.03	0.60	42.73	12.82	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
0.60	0.50	0.50	37.51	22.51	0.50	54.88	32.93	0.50	76.77	46.06	0.60	42.73	25.64	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
0.90	0.50	0.50	37.51	33.76	0.50	54.88	49.39	0.50	76.77	69.09	0.60	42.73	38.46	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
1.20	0.50	0.50	37.51	45.01	0.50	54.88	65.85	0.50	76.77	92.12	0.60	42.73	51.28	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
1.50	0.50	0.50	37.51	56.26	0.50	54.88	82.32	0.50	76.77	115.15	0.60	42.73	64.10	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
1.80	0.50	0.50	37.51	67.52	0.50	54.88	98.78	0.60	31.65	56.97	0.60	42.73	76.92	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
2.10	0.50	0.50	37.51	78.77	0.50	54.88	115.25	0.60	31.65	66.46	0.60	42.73	89.74	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
2.40	0.50	0.50	37.51	90.02	0.50	54.88	131.71	0.60	31.65	75.96	0.60	42.73	102.56	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
2.70	0.50	0.50	37.51	101.27	0.60	22.52	61.09	0.60	31.65	85.45	0.60	42.73	115.38	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
3.00	0.50	0.50	37.51	112.53	0.60	22.52	67.87	0.60	31.65	94.95	0.60	42.73	128.20	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
3.30	0.50	0.50	37.51	123.78	0.60	22.52	74.66	0.60	31.65	104.44	0.60	42.73	141.02	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
3.60	0.60	0.60	15.46	55.67	0.60	22.52	81.45	0.60	31.65	113.94	0.60	42.73	153.84	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
3.90	0.60	0.60	15.46	60.31	0.60	22.52	88.24	0.60	31.65	123.43	0.60	42.73	166.66	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
4.20	0.60	0.60	15.46	64.95	0.60	22.52	95.02	0.60	31.65	132.93	0.60	42.73	179.45	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
4.50	0.60	0.60	15.46	69.59	0.60	22.52	101.81	0.60	31.65	142.42	0.60	42.73	192.20	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
4.80	0.60	0.60	15.46	74.22	0.60	22.52	108.60	0.60	31.65	151.91	0.60	42.73	205.03	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
5.10	0.60	0.60	15.46	78.46	0.60	22.52	115.39	0.60	31.65	161.41	0.60	42.73	217.86	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
5.40	0.60	0.60	15.46	83.50	0.60	22.52	122.17	0.60	14.96	80.80	0.60	42.73	230.69	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
5.70	0.60	0.60	15.46	88.14	0.60	22.52	128.96	0.60	14.96	85.29	0.60	42.73	243.52	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58
6.00	0.60	0.60	15.46	92.78	0.60	22.52	135.75	0.60	14.96	89.78	0.60	42.73	256.35	0.50	14.58	86.26	0.50	14.58	86.26	0.50	14.58

4.3 The Model No.3.: Determination of optimal size of irrigation unit

The capacity of smallest electrically operated portable sprinkler irrigation units starts at about 6 L/S and goes up to about 60 L/S, while the total capacity of installed irrigation pumping plants having 3...8 pumps in one group starts at about 200 L/S and goes up to 1200 L/S. The actual size of irrigated land depending on main characteristics of irrigation pattern changes between 15...1500 HA among Hungarian production circumstances. The operation cost of irrigation plants considerably depends upon the size of irrigated land on one hand because of the high energy demand of water transport, and upon the fixed costs of pumping station /feeding canal, electric energy supplying, buildings etc./ on the other. The specific energy demand of water transport increases by growing area of irrigation plant, while the specific investment costs of pumping plant, in general, decreases by growing the capacity of it. The present average size of big sprinkler irrigation plants /1200-1500 ha/ was decided before the international energy and energy price crisis, thus the optimum size of electric energy intensive sprinkler irrigation plants should be overevaluated on the basis of steadily increasing energy prices and maximum saving of energy sources.

4.3.1 The objectives of computer calculations

The main objective of this computer program is to decide the optimum land size of irrigation plants, which is influenced by a great number of different parameters, as e.g.:

- technical and hydraulic factors,
- operational and irrigational practices,
- economical points and situations.

The most important problem of determination of the optimum size of irrigation unit on the basis of minimum energy design,

is that, most of the technical, irrigational, technological and economical factors influence each other, sometimes repeatedly. The general assumptions of this computer program are as follows: on the long-term basis the electrically operated pumping units are the most reasonable ones for sprinkler irrigation purposes in Hungary; the irrigation water is available from primary or secondary irrigation canals in the vicinity of which either many smaller or few larger irrigation plants can be established, the basic technical parameters of pumps, pipe-lines /size, pressure, materials etc./ will not be changed considerably.

The total energy necessary for operation of sprinkler irrigation machines can be applied partly in the form of electric energy and partly as hydraulic energy. In other words: the optimum size of irrigation plant depends basically on the difference of costs of energy losses in pipe-line systems and upon the related yearly ratio of investment costs of water and electric energy supplying and pumping plant and pipe-line systems.

If we consider the specific hydraulic energy demand of water transport as a function of irrigated land size then the specific energy requirement increases with growing land size, while the specific investment cost i.e. the yearly part of fixed operation cost decreases. It gives an understanding that among given conditions there should be an optimum solution for pumping capacity and land size of different sprinkler irrigation plants.

4.3.2 Mathematical relations for computer analysis

Step 1.: Calculation of irrigated land unit

The size of land unit irrigated in one run can be calculated as follows:

- the width of irrigation unit:

$$WIU = 2 \cdot NNL \cdot DNL \quad [M] \quad /4.27/$$

where: NNL - number of nozzles on one lateral

DNL - distance between nozzles on lateral /M/

- the length of irrigation unit:

$$LIU = NOL \frac{NSL}{2} \cdot DSL \quad [M] \quad /4.28/$$

where: NSL - number of settings of laterals

DSL - distance between settings of laterals /M/

NOL - number of simultaneously operated laterals

- the area covered by one nozzle:

$$ACN = DNL \times DSL \quad [SQM] \quad /4.29/$$

- the area of irrigation unit in one run:

$$AIU = WIU \cdot LIU \cdot 10^{-4} \quad [HA] \quad /4.30/$$

where: WIU - width of irrigation unit /M/

LIU - length of irrigation unit /M/

- the distance between hydrants on submains:

$$DHS = /3...4/ \cdot DSL \quad [M] \quad /4.31/$$

where: DSL - distance between stages of laterals /M/

- the irrigation intensity of lateral:

$$IIL = \frac{NSL \cdot DWA}{IRD \cdot DOH} \quad [MM/H] \quad , 4.32/$$

where: NSL - number of settings of laterals

DWA - depth of water application /MM/

IRD - irrigation days /DAYS/

DOH - daily operation hours /HRS/

- the required discharge of lateral:

$$RWL = \frac{2,78 \cdot AIU \cdot DWA}{IRD \cdot DOH \cdot NOL} \quad [L/S] \quad /4.33/$$

All these components are constant in one run of computer model and are not counted by the computer.

Input data: NNL = 10, DHS = 72 M
DNL = 24 M DWA = 60 MM
NOL = 3 IRD = 6 DAYS
NSL = 12 , DOH = 18 HRS
DSL = 24 M NIP = 3

Output data:

- the area covered by one nozzle:

$$ACN = 24 \times 24 \text{ SQM}$$

- the width of irrigation unit:

$$WIU = 2 \cdot 10 \cdot 24 = 480 \text{ M}$$

- the length of irrigation unit:

$$LIU = \frac{3 \cdot 12 \cdot 24}{2} = 432 \text{ M}$$

- the area of irrigation unit:

$$AIU = 480 \cdot 432 \cdot 10^{-4} = 20,7 \text{ HA}$$

- the distance between hydrants of submains:

$$DHS = 3 \cdot 24 = 72 \text{ M}$$

- the irrigation intensity of lateral:

$$IIL = \frac{12 \cdot 60}{6 \cdot 18} = 6,67 \text{ MM/H}$$

- the required water discharge of lateral:

$$RLW = \frac{2,78 \cdot 20,7 \cdot 60}{6 \cdot 18 \cdot 3} = 10,65 \text{ L/S}$$

Step 2.: Calculation of hydrant characteristics

The actual water discharge of lateral based on Dobos' formule can be calculated as follows:

- the total water discharge increments of lateral:

$$TWI = C2 \cdot NWN \quad [\text{L/S}] \quad /4.34/$$

where: C2 - designing constant depending on nozzle diameter and B factor of lateral tube /material diameter etc./

NWN - nominal water discharge of nozzle /L/S/

- the total water discharge of one lateral:

$$TWL = NNL \cdot NWN + C2 \cdot NWN \quad [L/S] \quad /4.35/$$

where: NNL - number of nozzles on the lateral

- the total head loss of lateral:

$$HLL = C4 \cdot NWN^2 \quad [M] \quad /4.36/$$

where: C4 - designing constant depending on nozzle diameter and B factor of lateral tube

- the head loss in connecting pipe:

$$HLC = B \cdot TWL^2 \cdot CPL \quad [M] \quad /4.37/$$

where: CPL - connecting pipe length /M/

B - designing factor for connecting pipe

- the total pressure demand at hydrant:

$$PDH = PLN + HLL + HLC \quad [M] \quad /4.38/$$

where: PLN - pressure at last nozzle /M/

HLL - total head loss in lateral /M/

HLC - head loss in connecting pipe /M/

All the above given parameters are constant on the course of this computer analysis and are not calculated by computer

Input data:

NNL = 10
 NWN = 1,31 L/S /TISZA-II., Ø 8,6 MM at 30 M/
 DNL x DSL=24x24 M CPL = 31,2 M
 B = $60 \cdot 10^{-5}$ /for Ø 85 MM steel tube/
 B = $30 \cdot 10^{-5}$ /for Ø100 MM steel tube/
 C2 = 0,34 /for B = $60 \cdot 10^{-5}$ and Ø 8,6 MM/
 C4 = 4,22 and 5,77 /for B= $60 \cdot 10^{-5}$ and Ø 8,6 MM/

Output data:

TWI = $0,34 \cdot 1,31 = 0,44$ L/S
 TWL = $10 \cdot 1,31 + 0,44 = 13,54$ L/S
 HLL = $\frac{4,22+5,77}{2} \cdot 1,31^2 = 8,57$ M
 HLC = $60 \cdot 10^{-5} \cdot 13,54^2 \cdot 31,2 = 3,43$ M
 PDH = $30 + 8,57 + 3,43 = 42$ M

The basic principle of lateral design

- the water discharge of nozzle:

$$Q = \mu_1 \cdot f_1 \cdot \sqrt{2 \cdot g \cdot H} \quad [L/S] \quad /4.39/$$

$$H = A_1 \cdot Q^2 \quad [M] \quad /4.40/$$

where: μ_1 - nozzle constant /0,93/

f_1 - cross section of nozzle /cm²/

A_1 - nozzle factor /23,33 m·s²/l² if Ø 8 mm/

- the head loss of lateral pipe:

$$h_v = \frac{v^2}{2g} \lambda \frac{1}{D} = B \cdot Q^2 \cdot l \quad [M] \quad /4.41/$$

where: λ - the friction loss factor

l - the length of pipe /m/

B - the pipe factor / $25 \cdot 10^{-5}$... $90 \cdot 10^{-5}$ /

Step 3.: The configuration of examined irrigated model lands

According to the Fig. 4.6 six different layouts are examined. The total area of them has been built up from various number of irrigation units, area of which was calculated in Step 2., and being: $AIU = WIU \cdot LIU = 480 \times 432 = 20,7$ HA. The largest irrigation plant, as an extreme high one is 2986 HA, and the smallest is 373 HA. The most important characteristics of examined irrigation plants are given in Table 4.5

The irrigation plants are symmetrically arranged and in this way the design of the pipe-line system is carried out only for one critical path of each variation, having the largest loading from irrigation operation point of view. The Fig. 4.7 includes the schemes of critical ways and operation parameters necessary for computer calculation.

The basic input data for designing the pipe-line systems are included in Appendix 4.8. The configuration of a given irrigation pipe-line system is determined by the following parameters:

- the number of main lines /NML/
- the number of submain lines on each main /NSL/
- the length of main lines' sections /WIU/
- the length of submains' sections /DHS/
- the number of hydrants on submains
- the water discharge of hydrant /TWL/
- the number of hydrants in operation /NOL/

For computer calculations of irrigation plants different from examined ones, the necessary input data should be developed and given according to the pattern followed in Appendix 4.8. The computer programme for Model No.3 is presented in Appendix 4.9, while the flow diagram is given in Fig. 4.8.

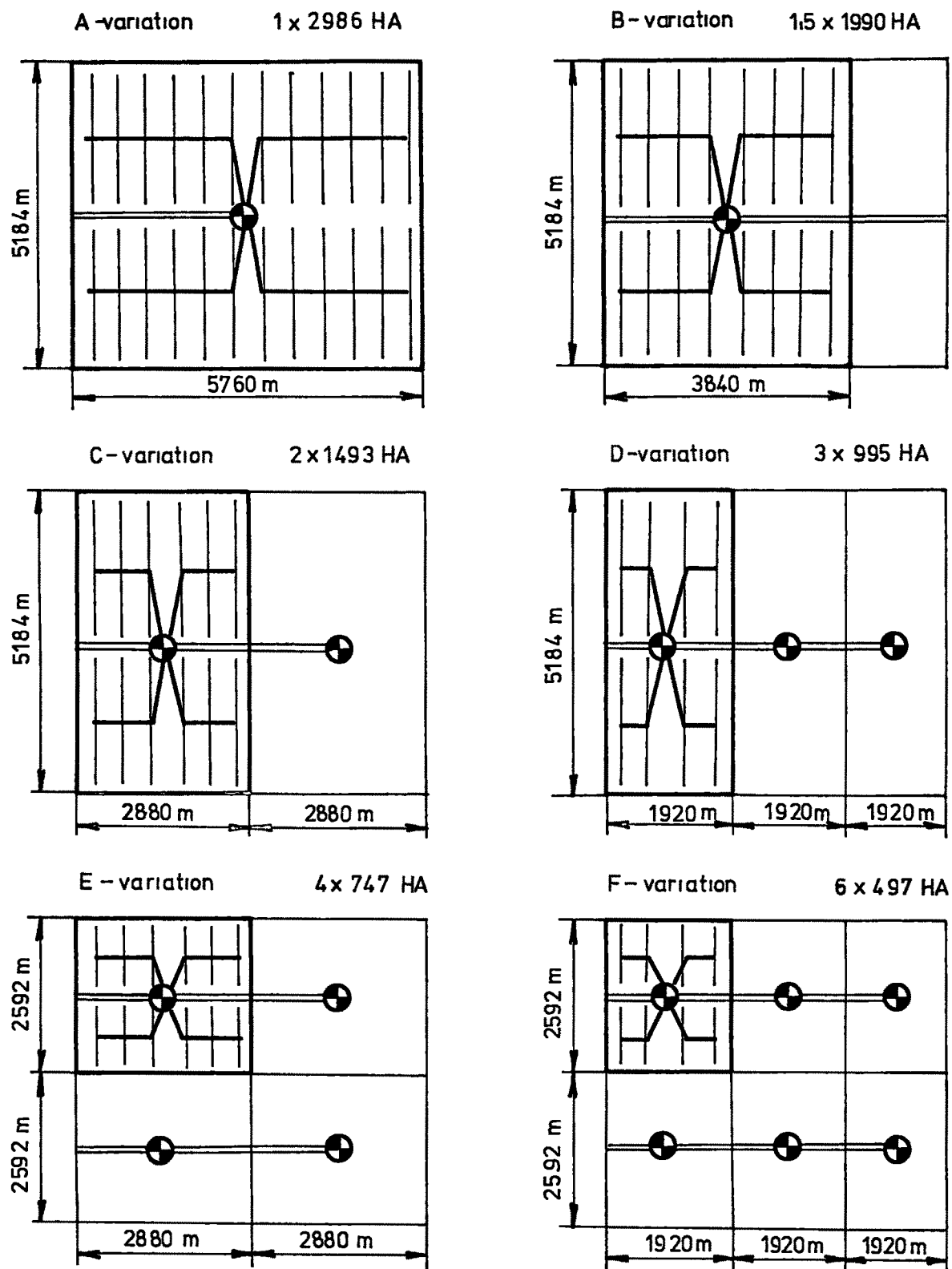


Fig 4.6 The examined variation of irrigation units

The overall characteristics of examined irrigation
model plants

Table 4.5

Variation No. of irrigati- on units NIU	Mains		Submains		No. of hydrant		Area of irri- gation plant AIP /HA/	Total water- discharge TWD /CUM/S/	
	No. NML	Length MPL	No. NSL	Length SPL	Total TNH	Operated ONH			
A	144	4	3718	12	1260	864	144	2986	1,944
B	96	4	2758	8	1260	576	96	1990	1,296
C	72	4	2278	6	1260	432	72	1493	0,972
D	48	4	1798	4	1260	288	48	995	0,648
E	36	4	1651	6	612	216	36	746	0,486
F	18	4	1171	4	612	144	24	497	0,324

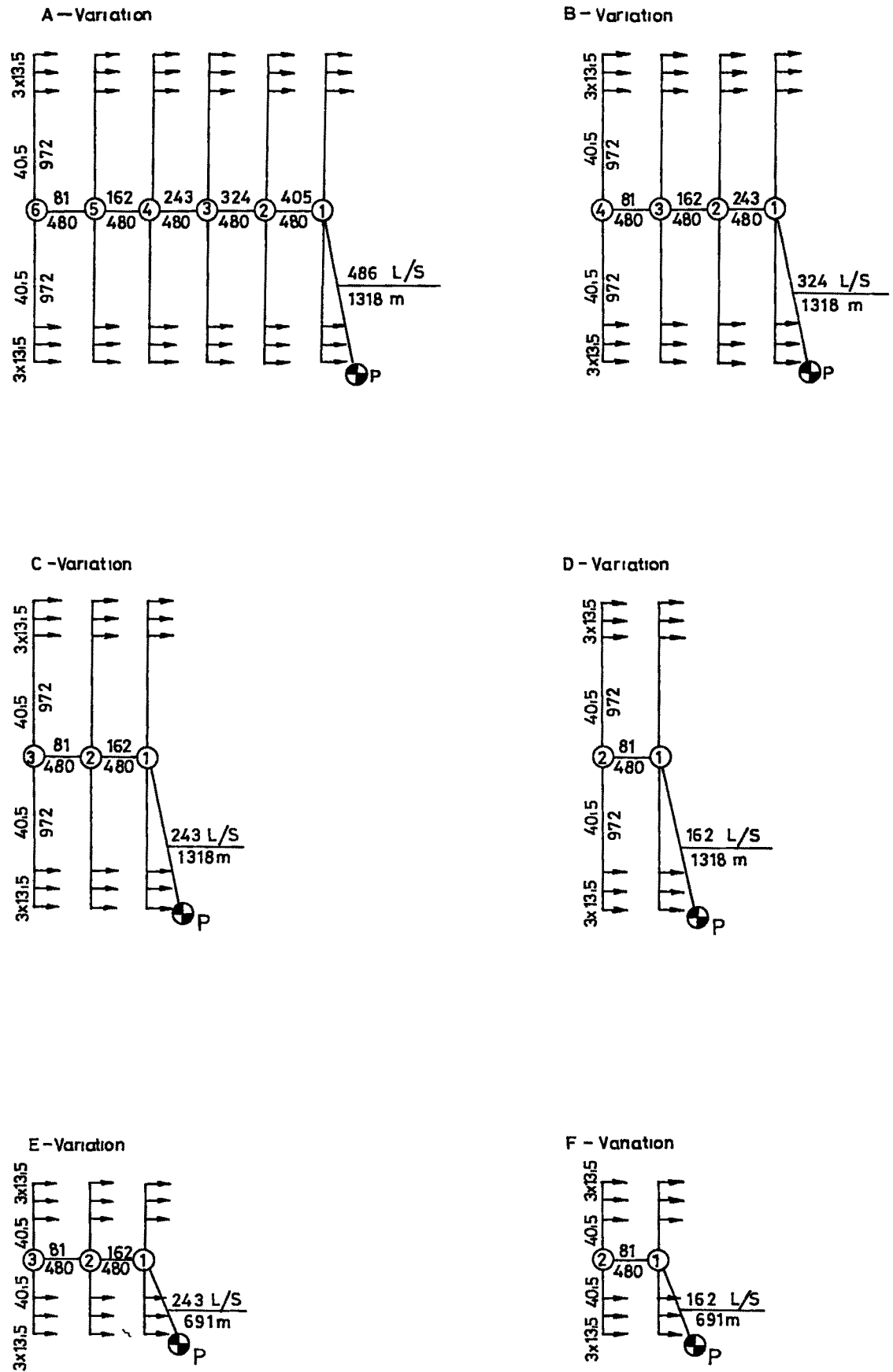


Fig 47 Schematic of critical operation path of pipe network

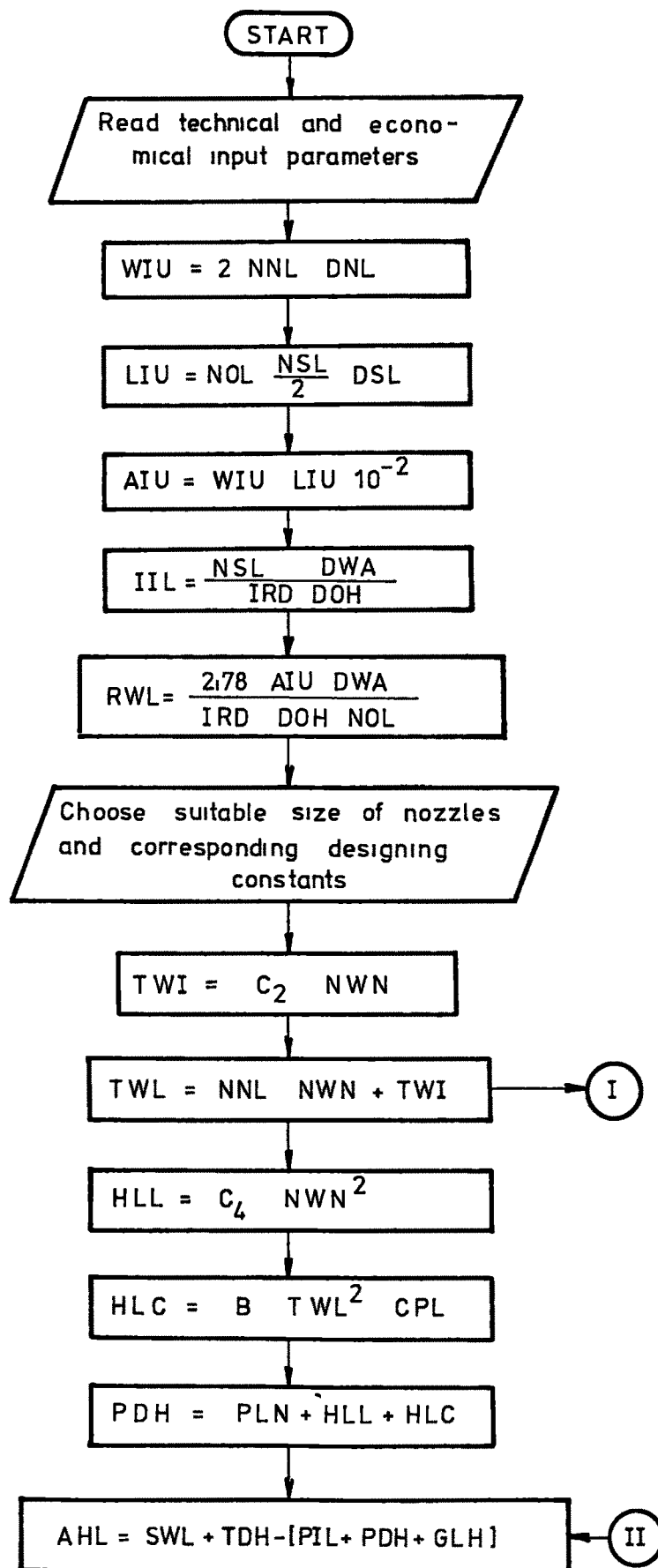


Fig 48 Flow diagram for Computer program of Model No 3

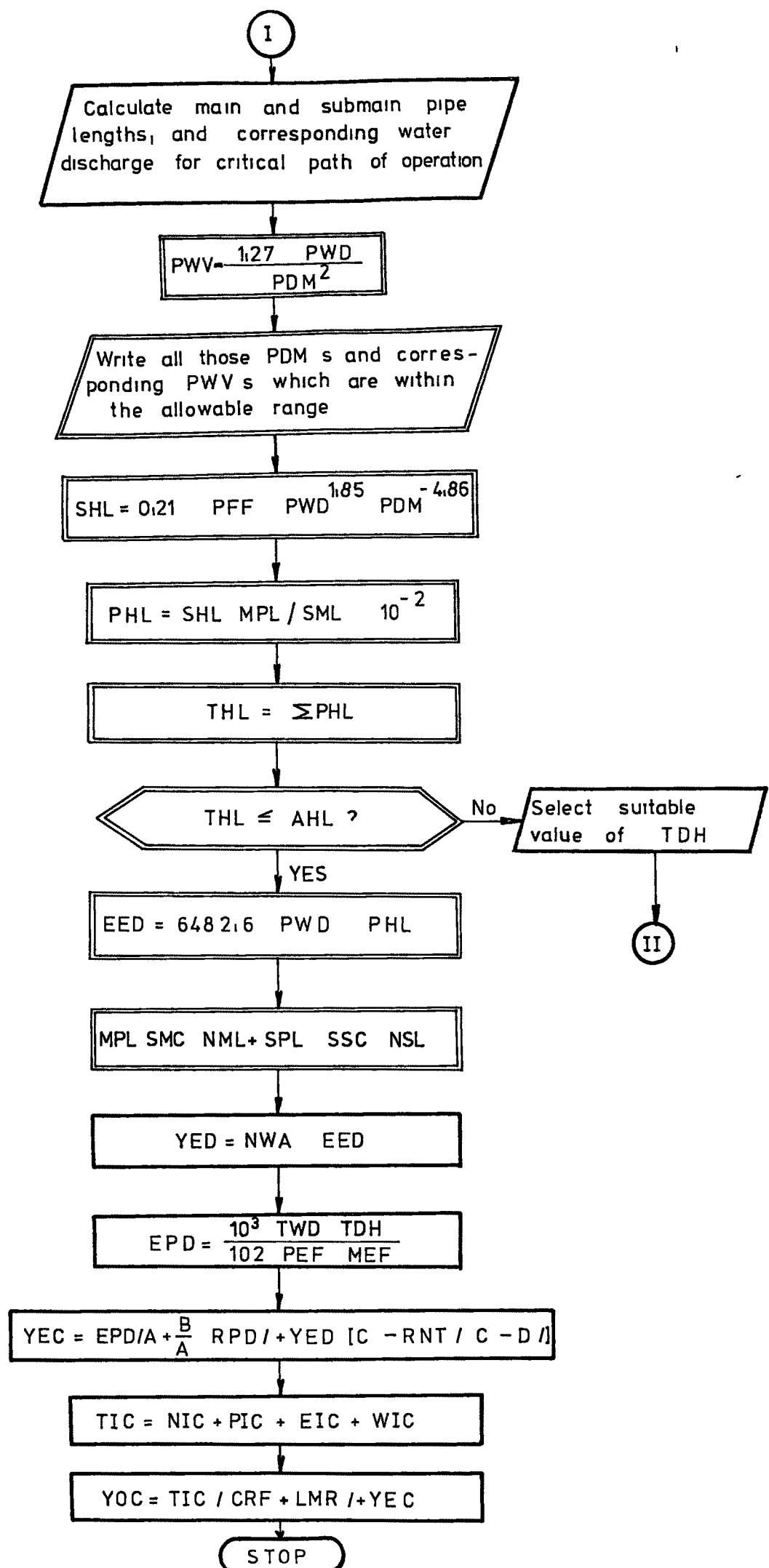


Fig 4.8 Flow diagram for Computer program of Model No 3

Step 4.: Details of computer analysis

Based on preliminary calculations the most important steps of computer analysis are, as follows:

- the calculation of
 - Pipe section Water Velocity /PWV/
- the selection of
 - Pipe Diameters /PDM/ to be adopted
- the calculation of
 - Specific Head Loss of each section /SHL/
 - Pipe section Head Loss /PHL/
- the selection of section diameters resulting:
 - Total Head Loss maximum /THL/
 - Total Head Loss minimum /THL/
- the printing out of following parameters: /Appendix 4.10/
 - pipe section number /INPUT/
 - Pipe section Water Discharge /INPUT/
 - Pipe section Length /INPUT/
 - Pipe section Diameters /PDM/ all suitable
 - Pipe section Water Velocity /PWV/ for suitable PDM
 - Specific Head Loss /SHL/ for all suitable PDM
 - Pipe section Head Loss /PHL/ for all suitable PDM
 - Total Head Loss /THL/ minimum and maximum
- the calculation and printing out of
 - Electric Power Demand /EPD/
 - Yearly Electric energy Demand /YED/
 - Yearly Electric energy Cost /YEC/
 - Total Investment Cost /TIC/
 - Yearly Operation Cost /YOC/
- the calculation and printing out of
 - Specific Electric Power Demand /SPD/
 - Specific electric Energy Demand /SED/
 - Specific electric Energy Cost /SEC/
 - Specific Investment Cost /SIC/
 - Specific Operation Cost /SOC/

Step 4.1 Pipe section Water Velocity /PWV/:

$$PWV = \frac{4 \cdot PWD}{\pi \cdot PDM^2} \quad [M/S] \quad /4.42/$$

where: PWD - pipe section water discharge /CUM/S/ from
Appendix 4. .

PDM - pipe diameters /M/ from Appendix 4.8.

Only those pipe diameters are allowed to apply water velocity
of which are in the range of

$$0,5 \leq PWV \leq 2,5 \text{ M/S}$$

Printing out: the suitable pipe section diameters /PDM/ and
the pipe section water velocity /PWV/ belonging
to them

Step 4.2 Specific Head Loss /SHL/ of any section:

$$SHL = 0,21 \cdot PFF \cdot PWD^{1,85} \cdot PDM^{-4,86} \quad [M/100 M] \quad /4.43/$$

where: PFF - pipe friction factor /0,7 for asbestos cement
and 0,55 for PVC pipes/

PWD - pipe section water discharge /CUM/S/ as in Step
4.1

PDM - pipe diameter /M/ selected in Step 4.1

Step 4.3 Pipe section Head Loss /PHL/

$$PHL = 10^{-2} SHL \cdot MPL \text{ or } PHL = SHL \cdot SPL \cdot 10^{-2} [M] /4.44/$$

where: SHL - specific head loss /M/100 M/ from Step 4.2

MPL - main pipe section length /M/ from Appendix 4.8 .

SPL - submain pipe section length /M/ from Appendix 4.8.

Printing out: the specific head loss and pipe section head loss
for all suitable diameters

Step 4.4 Total Head Loss /THL/

$$THL = \sum PHL \leq AHL \quad [M] \quad /4.45/$$

where: $\sum PHL$ - total head loss of mains and submains /M/

AHL - allowed head loss /M/ being constant: 30 M

By the help off Ijjas' formula:

$$AHL = SWL + TDH - PIL - PDH - GLH \quad [M] \quad /4.46/$$

where: SWL - suction water level /M/

TDH - total discharge head of pump /M/

PIL - pump inside losses /M/

PDH - pressure demand at hydrant /M/

GLH - geographical level of hydrant /M/

most of these parameters being constant on the course of computer analysis; e.g.:

$$AHL = 125 + 85 - 3 - 42 - 135 = 30 \text{ M}$$

Printing out: The components of minimum and maximum values of THL into the rows of given diameters.

Step 4.5 Electric power Demand /EPD/

$$EPD = \frac{10^3 \text{ TWD} \cdot \text{TDH}}{102 \cdot \text{PEF} \cdot \text{MEF}} \quad [KW] \quad /4.47/$$

where: TWD - total water discharge /CUM/S/ from Appendix 4.8

TDH - total Dynamic head /M/

PEF - pump efficiency factor /0,7/

MEF - motor efficiency factor /0,7/

Step 4.6 Yearly Electric energy Demand /YED/

$$YED = NWA \cdot NIP \cdot IRD \cdot DOH \cdot EPD = 324 \cdot NWA \cdot EPD \quad [KWH] \quad /4.48/$$

where: NWA - number of irrigation water application /1, 2, 3, 4 times/

NIP - number of irrigation periods /3/

DOH - daily operation hours /18 HRS/

IRD - irrigation days /6 DAYS/

$$NIP \cdot IRD \cdot DOH = 3 \cdot 18 \cdot 6 = 324 \text{ HRS}$$

Step 4.7 Yearly Electric energy Cost /YEC/

$$YEC = EPD /A + \frac{B}{A} \cdot RPD/ + YED \cdot [C - RNT /C-D][FT] /4.49/$$

where: EPD - electric power demand /KW/
 YED - yearly electric energy demand /KWH/
 RPD - ratio of peak power demand /RPD = 0/
 RNT - ratio of night tariff /RNT = 0,20/
 A - power cost day period /270 FT/KW/
 B - power cost peak period /750 FT/KW/
 C - energy cost day period /0,70 FT/KWH/
 D - energy cost night period /0,70 FT/KWH/

Step 4.8 Total Investment Cost /TIC/

$$TIC = NIC + PIC + EIC + WIC \quad [FT] \quad /4.50/$$

where: NIC - pipe network investment cost /FT/
 PIC - pumping plant investment cost /FT/
 EIC - energy supplying investment cost /FT/
 WIC - watersupply investment cost /FT/

$$NIC = MPL \cdot SMC \cdot NML + SPL \cdot SSC \cdot NSL \quad [FT] \quad /4.51/$$

where: MPL - main pipe length /M/
 SPL - submain pipe length /M/
 NML - number of main lines from Table 4.5
 NSL - number of submain lines from Table 4.5
 SMC - specific main line investment cost /FT/M/
 SSC - specific submain investment cost /FT/M/

Step 4.10 Yearly Operation Cost /YOC/

$$YOC = TIC /CRF + LMR/ + YEC \quad [FT] \quad /4.52/$$

where: CRF - capital recovery factor /0,132 for 15 years life cycle and 10 per cent of interest/
 LMR - labour, maintenance and repairing /0,05 for average operation conditions/

4.3.3 The model outputs and interpretation

With the help of computer program No.3. outlined in Step 4., firstly the pipe head loss /PHL/ for possible minimum and allowed maximum pipe diameter variations were determined, as it can be seen from computation results tabulated in Appendix 4.10. Along with the calculation of pipe head loss components, the electric energy demand /EED/ was calculated and tabulated, too, for each suitable pipe section diameter. The largest suitable diameter belongs to the minimal value of EED and of PHL, while the smallest possible pipe section diameter /PDM/ was determined by the condition of allowed head loss /AHL/ for the total route in question. The minimum value of total head loss /THL/ is the sum of those section PHL components which belong to largest applicable pipe diameters, while the maximum value of total head loss is the sum of section pipe head loss components belonging to the smallest applicable pipe diameters. The maximum and minimum electric energy demand for water transport through pipe section was decided in the same way. Simultaneously the maximum and minimum value of network investment cost /NIC MIN and NIC MAX/ was calculated and printed out by computer, too. Finally, the results of outlined computer calculation, completed by specific energy demand of water transport /MIN and MAX/ and specific investment cost /MAX and MIN/ related to one hectar of irrigated land was calculated by hand. The intermediate results of these calculations are given in Table 4.6.

The further calculations, completed without computer programming, are based on overall characteristics of examined irrigation plant arrangements /Appendix 4.11/, where all the necessary technical and economical parameters are related equally to 3000 HA of irrigated land. The specific investment cost of pumps and pump station appliances /PIC/, electrification /EIC/ and water supply /WIC/, generally increases with the decreasing of nominal capacity of pumping units, and the MIN investment cost of pipe lines slightly decreases with the decrease of unit area

The computed characteristics of examined irrigation model
plants for one main lines

Table 4.6

Variation /area of one main/	Total Head Loss		El.En.Demand		Netw.Inv. Cost		Spec.En. Dem.		Spec.Inv. Cost	
	MIN M	MAX M	MIN KWH	MAX KWH	MIN MFT	MAX MFT	MIN KWH/HA	MAX KWH/HA	MIN FT/HA	MAX FT/HA
A /750 HA/	7,58	28,61	18573	68672	24342	30433	25,0	91,6	32456	40577
B /500 HA/	4,87	29,04	7659	49875	15677	20933	15,3	99,7	31354	41866
C /375 HA/	4,25	28,58	4571	33689	11785	16049	12,2	89,8	31427	42797
D /250 HA/	3,66	29,19	2944	24123	7786	10697	11,8	96,5	31144	42788
E /187 HA/	3,21	28,01	2001	17297	5688	8188	10,7	92,5	30417	43786
F /125 HA/	3,07	28,67	1150	11988	3708	5625	9,2	95,5	29664	45000

irrigated from one pumping unit. The total investment cost is determined for MIN and MAX pipe network investment.

The yearly electric energy demand /YED/ of different layouts is based on MIN and MAX specific energy demand given by computer calculation /Table 4.6/, however these values were increased with 200 KWH/HA, necessary for accomplishing 80 M of dynamic head, i.e. for suction of water and feeding of sprinklers, if the water application is 600 CUM/HA. Further on, the yearly energy demand /YED/ and electric energy cost /YEC/ for 600, 1200 and 3000 CUM/HA of water application was determined /Appendix 4.12/ for 1,0 FT/KWH and 3,0 FT/KWH specific energy cost. The fixed part of yearly operation cost includes three components: machines /15 years life and CRF = 0,132/, establishments /25 years life CRF = 0,112/ and maintenance, which are summed up and related to one hectare of irrigated land. /Appendix 4.13/. Finally, in Appendix 4.14 and 4.15 the yearly total cost /YOC/ is given for minimum investment /MIN INV/ and minimum energy /MIN EN/ design, taking 600, 1200 and 3000 CUM/HA water application as well as 3,0 FT/KWH and 6,0 FT/KWH specific energy cost.

As it is obvious from final results of modelling, the total specific cost of operation, in general, slightly increases with decreasing the area of one pumping unit, e.g. with 1200 CUM/HA and 3,0 FT/KWH from 7741 to 9913 FT/HA and from 7600 to 11112 FT/HA for MIN investment and MIN energy design, respectively. The optimum size of irrigated land can be found about 1500 HA of irrigated land from one pumping unit.

As regards the specific cost of water application it is most sensible for the utilization of the whole establishment, i.e. it depends basically on the yearly water application.

There is no significant difference between the MIN investment and minimum energy design; if the water utilization is 1200 CUM/HA, the total water application cost, including also the ratio of national investments, changes from 6,5 FT/CUM up to 8,3 FT/CUM for minimum investment variation and from 6,3 to 9,3 FT/CUM for minimum energy variation, with 3,0 FT/KWH specific cost of electricity. If the specific cost of electricity or the yearly utilization of pumping unit decreases the specific cost of minimum investment variation becomes little more favourable, however if the cost of electricity goes up considerably /e.g. as an upper limit up to 6,0 FT/KWH/, the minimum energy design becomes more economical.

Summing up the conclusions derived from model analysis it could be stated that parallel with the steady increase of energy prices, including naturally the price of electricity, the basic principles of former practice on the field of irrigation plant design should be overevaluated. Among the future possible conditions when considerable increase of electric energy price and high utilization of irrigation pumping units could be expected, instead of the minimum investment cost design the minimum energy demanding solutions should be preferred.

5. RESULTS

On the basis of my own research activity outlined in the Chapter 3. and 4. the following most important conclusions are presented.

1. Due to the complexity of measuring energy consumption exclusively for irrigation purposes, there is no statistical data available regarding actual energy utilization for irrigation water supply and for on-farm irrigation on national level. But as an estimate of the present installed power capacity of the pumps used for irrigation water supply, can be approximated to some 200 - 220 MW and 35 - 38 MW for diesel and electricity operated pumps respectively. The total yearly electric energy demand of irrigation according to my investigations is about 20 - 30 million kWh and that of diesel oil is 30 - 40 thousand tons. Based on calculated energy requirement of irrigation and considering average prices of all sources of energy, the total cost of direct energy demand for last few years is estimated as 135 - 180 million forints, and 25 - 40 million forints per annum towards diesel oil, and electric energy requirement, respectively. Assuming further increasing capacity of high pressure electrically operated installed sprinkler systems and overall increase in the pumped irrigation hectareage, the middle-term electric energy demand of irrigation in Hungary will be about 60 - 70 million kWh, and the diesel oil energy requirement some 70 - 80 thousand tons. Thus, it is clear from these data that irrigation is and will remain one of the largest energy consumer in Hungarian agriculture, too and therefore serious efforts should be undertaken to maintain systematic and detailed records of energy utilization in the whole irrigation process, which would facilitate in efficient use of limited energy sources for further irrigation development.

2. The selected site of TISZA-II. establishment, i.e. the NAGYKUNSAÁG, NK-XII. subsection concerning to SZOLNOK TRVTV company, proved to be a reliable place for irrigation energy data collection. The overall energy demand of irrigation which includes energy to supply water from source up to field and to distribute water over the field, mostly being sprinkler method, is influenced by ratio of water lifting and sprinkler irrigation pumping. The overall average specific energy consumption was found to change between 0,05 to 0,09 kWh/m³ and 0,017 to 0,035 kg/m³ for electrical and diesel operated pumps respectively. Thus the total pumping energy requirement of irrigation of one hectare of land comes to be in the range of 300 - 500 kWh/ha /1080 - 1800 MJ/ha directly used energy, and 3130 - 5220 MJ/ha including the losses of electric energy production and supplying/ or 50 - 120 kg/ha /2090 - 5030 MJ/ha/ which parameters considerably high compared to the energy demand of other agricultural processes and in this way the irrigated crop production is 2 to 4 times more energy demanding than the non-irrigated plant production.

3. In the command of SZOLNOK TRVTV company there are 57 large agricultural pumping units, including 157 electrically operated /76 lifting and 89 sprinkler pumps/ and 101 diesel /91 lifting and 10 sprinkler/ pumps of high capacity. The primary water source is exclusively surface /river and canal/, therefore suction lifts for water lifting are not high, i.e. only 5 to 12 m. The average electric energy demand for water lifting and sprinkler distribution was measured as 0,015 to 0,030 kWh/m³ and 0,30 - 0,32 kWh/m³ respectively. The same figures for diesel operated pumps were 5,7 to 6,6 g/m³ and 78 g/m³, respectively.

4. The detailed energy and water consumption investigations of the six sprinkler pumping units constituting the MEZŐHÉK-TISZAFÖLDVÁR irrigation plants provided very valuable

information on energy utilization pattern of most important irrigation method in Hungary. The average energy demand and energy cost in these irrigation units was determined by analyzing:

- the utilization of irrigated land capacity,
- the utilization of installed pumping capacity,
- the realization of planned water discharge, and
- the utilization of contracted electric power demand.

The results of evaluations are expressed as indices of specific energy cost of water application Ft/m^3 and related specific cost of electricity Ft/kWh . The average utilization of technically equipped land of the six irrigation units, during the last five year period /1976-1980/ was 72 %, and it was changing from 53 to 94 %. While the capacity utilization factor based on planned water discharge was changing from 28 to 93 %, with the average of 51 percent. Both, the land and pumping capacity utilization depend upon weather conditions and cropping pattern of the given year. In consequence of the low utilization factors of pumping units area and pumping capacity, electric power demand utilization is also affected. The contracted electric power could not be utilized resulting in to high specific energy cost of water application and increased specific cost of electricity as seen from Fig. 5.1 and Fig. 5.2. It is quite clear from these figures that the specific energy cost of water application Ft/m^3 and specific cost of electricity Ft/kWh are in hyperbolic relation with the specific water application m^3/ha . It means that at high specific water application lower specific cost could be realized, but this may be 3 to 4 times higher than the normal value as the utilization factor drops down by 20 - 25 percent. It can be concluded therefore that the total installed pump capacities at these six units were substantially overcalculated, resulting in higher cost of operation, i.e. in too expensive irrigation.

5. The average specific energy and energy cost requirement and average energy requirement of water application per hectare are 0,23 - 0,32 kWh/m^3 , 0,30 - 0,80 Ft/m^3 and 200 - 372 kWh/ha

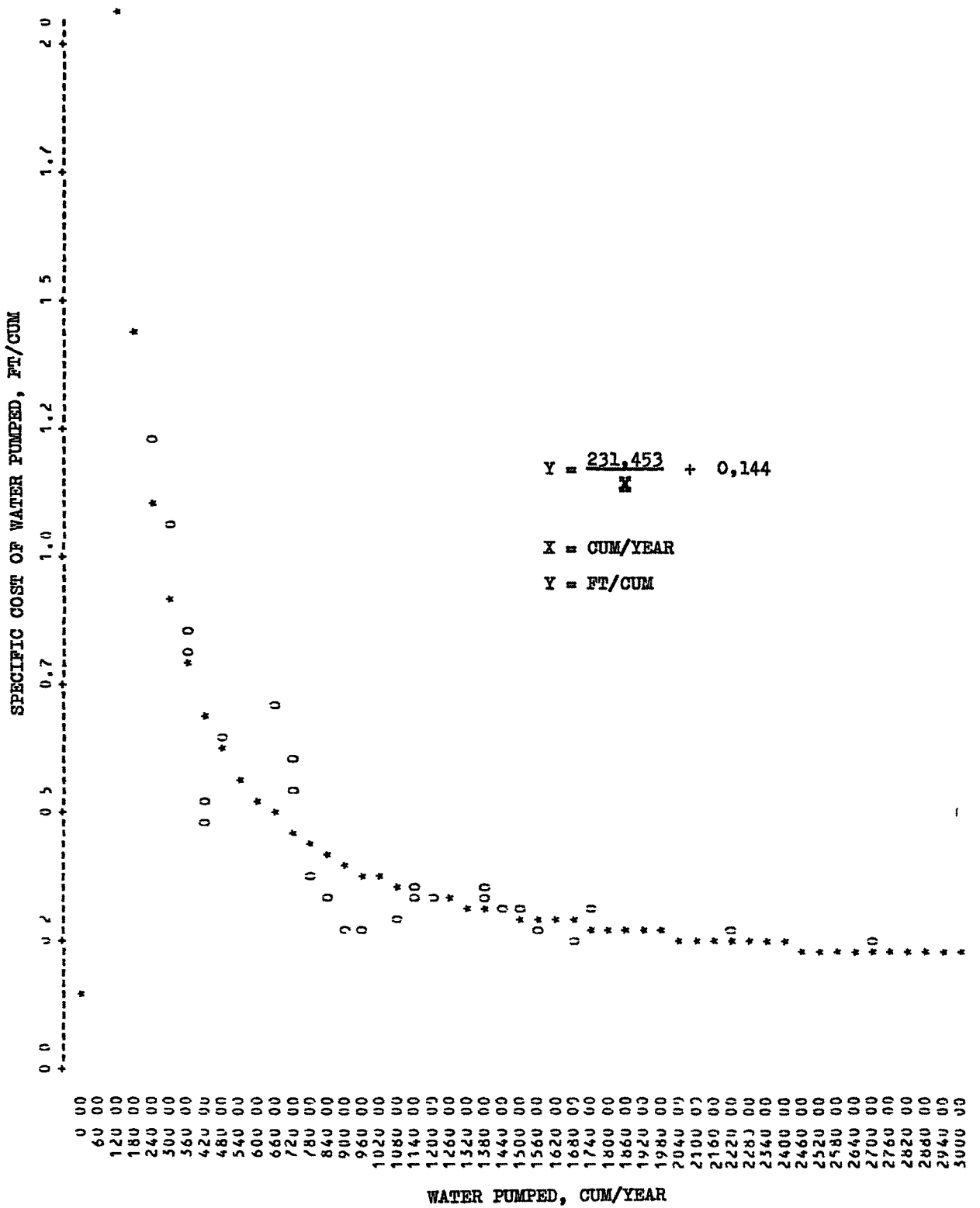


Fig. 5.1 Relationship between yearly water pumped and specific cost of water

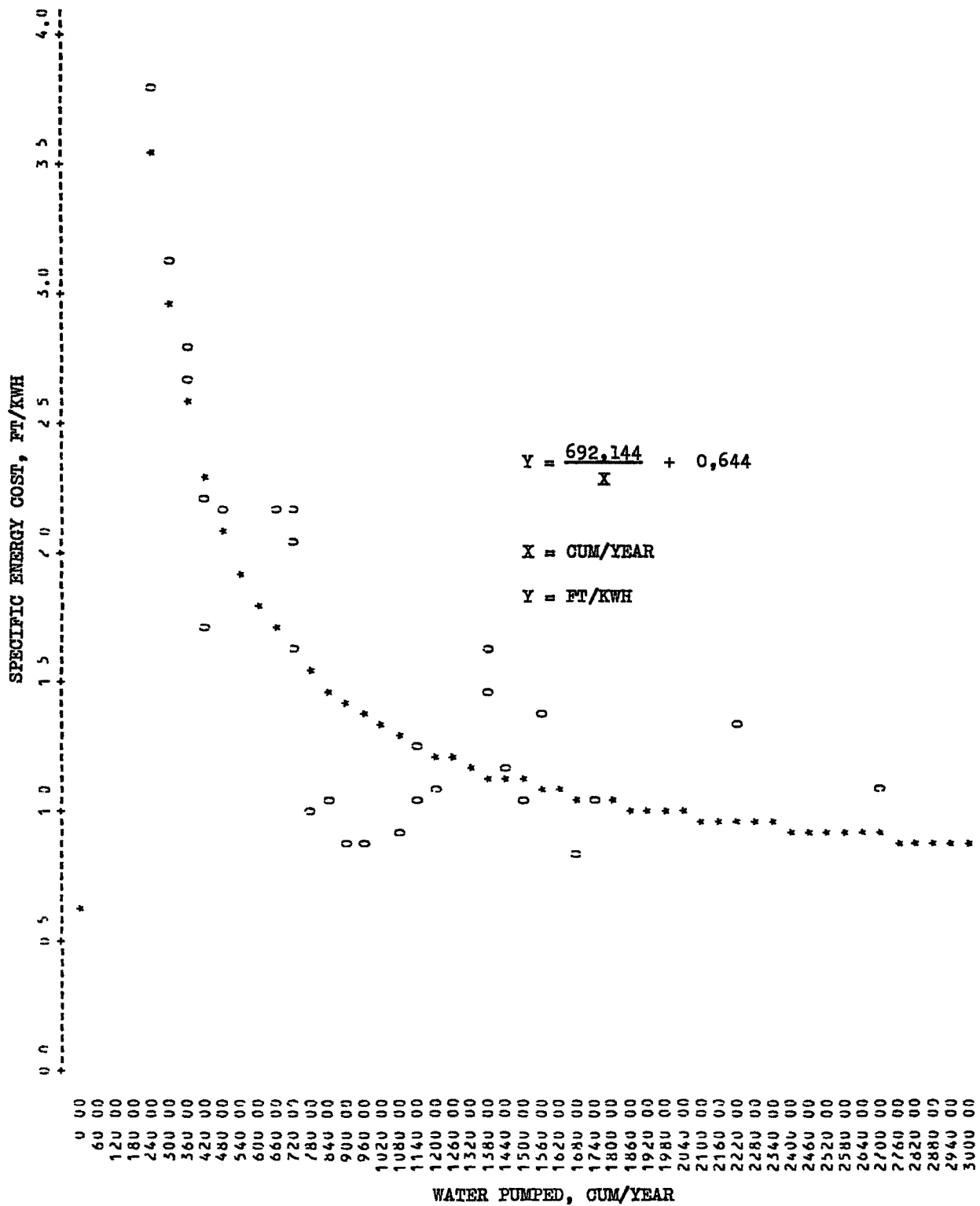


Fig.5.2 Relationship between yearly water pumped and specific energy cost

respectively, which are lower compared to international figures. Thus in these semi-permanent sprinkler irrigation units main problem is not of reducing specific energy demand /kWh/ha/, but lowering the high specific energy cost of water application /Ft/m³/ and specific cost of electricity /Ft/kWh/. In further establishments some suitable modifications in the existing design criteria should be made. Assuming pumping capacity and electric demand utilization factor approaching to 90 percent and for the present tariff system and irrigation practices, on the basis of theoretical calculations, the various specific desirable minimum values related to optimum operation of semi-permanent sprinkler irrigation systems are:

0,35 to 0,40 kWh/m³

0,35 to 0,45 Ft/m³

1,30 to 1,50 Ft/kWh

6. The average energy cost is very sensible for the determination of electric power /kW/ demand of irrigation pumping unit. Therefore in those months when there was hardly irrigation at all, the monthly average price of electricity reached 5,50 - 8,60 Ft/kWh, and the energy cost of water application 2,50 - 5,30 Ft/m³, which are extraordinary higher than the reasonable average, and more then 3,5 to 4,5 times greater than the electricity price being taken into consideration when the sprinkler irrigation units are designed by the help of different computer minimalization programmes. It is to note that, in case of the two pumping

units of MEZŐHÉK, for the year 1979, even though the yearly utilization factors of actual water discharge to the planned water demand exceeds 100 percent, the yearly utilization of pumping capacity factors were less than 50 percent, which is again resulted from excessively high installed total pump capacity.

The monthly values of water pumped and energy consumed are highly varying from month to month, from year to year and from unit to unit and they are basically the function of area irrigated, cropping pattern, and weather conditions. No special trend or peak periods of water demand were observed in the month wise water demand distribution of examined six sprinkler irrigation units.

7. The average daily energy demand depends basically upon the amount of water pumped, the actual average operating pressure at the pumps i.e. upon the distance of irrigated land from pumping center, number of submains and hydrants operating on the given main, which decides the extent of friction losses occurring in pipe network. Daily average energy consumption and water pumped, and specific energy consumption values greatly changes from day to day even for the same pumping unit and they proved to be 1000 - 6500 kWh/day, 2500 - 25000 m³/day, and 0,13 to 0,65 kWh/m³, respectively. From Fig. 3.10 and Fig. 3.11 it can be observed that there is an interesting relation among daily values of energy used, water pumped and average specific energy demand. It is to point out that when average amount of water pumped is more than 12000 m³/day, specific energy consumption values are substantially low. In general it is observed that the water pumped /m³/day/ has inverse relation with specific energy demand /kWh/m³/. This is due to the fact that on low water demand days, most of the times Basic pumps are operated which have lower pumping unit efficiency than Main pumps. Thus by operating main pumps for irrigation purposes lower energy consumption can be realized.

8. Pumping unit efficiency /PUE/ is one of the most important index of evaluating energetical performance of pump operation, and has direct influence on energy consumption. In order to calculate PUE, it is necessary to know the real average operation pressure during the given period. The procedure of using X-Y digitizer and further computerized evaluation proved to be satisfactory for calculating accurate average values of discharge rate and pressure and thus the pumping unit efficiency. This procedure can be followed for any length of period if the strip diagrams for that period are available. Results of the short duration experiments show that the PUE varies between 50 - 68 %, giving an average value of 62 %, which is a satisfactory situation for optimum energy consumption. Although the PUE values around 70 % are expected for such a pumping unit. It is also observed that when the pump or pumps were operated around their nominal capacities the PUE was also higher.

9. Due to changing cropping pattern, area irrigated at one time, and location of irrigated area relative to the pumping center, the irrigation water demand and therefore the water discharge through a given main pipe and submain pipes changes within very wide limits. Consequently, the main pipe capacity utilization was as low as 12.5 percent on some days. In general only 25 - 50 % pipe capacity was utilized /Fig. 3.15/, which is again in consequence of overcalculation of pumping capacity and lower utilization factor of land capacity. Although this situation is favourable from energy demand side, due to minimum friction losses, it is disadvantageous on the side of fixed annual investment cost. In case of smaller pumping units pipe capacity utilization could be higher.

10. When hydrant flow is throttled pumping water demands increased amount of energy. It was found that the specific energy consumption may be as much as 20 to 88 percent higher in case of throttled operation than that of fully opened hydrant operation. Beyond certain limit of throttling lateral

water pressure is not sufficient to operate the sprinklers at desired pressure. Therefore it is recommended that all the hydrants /especially nearer to pumping center/ should always be operated at their full discharge and throttling should be avoided.

11. The role of automatic control of operation of these pumping units in reducing the energy and water demand is questionable. According to the basic plan the purpose of the Basic pumps is to maintain certain basic pressure in the system /0,75 to 0,93 MPa/ during the irrigation season. But in practice this is hardly realized, and on the other hand they were operated for satisfying irrigation water demand. At pumping unit of KUNGYALU for example there is no automatic control instrumentation, but it has given optimum desirable values of specific energy consumption compared to the automatically operated MEZŐ-HEK-I. unit. The automatic control devices installed in these units do not help in reducing water requirement or water losses of irrigation.

Sprinkler laterals are not operated at recommended pressure, various sizes and numbers of sprinklers are used on the laterals. There are lot of leakages at hose connection, drain valves do not close properly. It is not known whether the given hydrant discharge and pressure are suitable for the given lateral operation. The depth of water application, therefore greatly differs from the planned one. It was experienced that the actual daily operation hours normally range from 8 to 14 hours and pumps are seldomly operated for 18 hours. The peak electric hours operation is strictly prohibited, but night operation hours are not utilized, which could further help in decreasing energy bills, beside reducing evaporation and wind drift losses of water.

Since these instruments are very useful in checking pump operation and also in counting total amount of water pumped

and energy consumed for billing purposes and research purposes too, care should be taken in keeping them in operating conditions. Thus in the so called up-to-date sprinkler irrigation pumping units there is a great need of further extending scientific water management techniques. Advance techniques of scheduling irrigation water application by computer processing of soil moisture, crop growth, weather data etc. should be adopted. Automatic or semi-automatic instrumentation should be developed for facilitating accurate and desired quantities of water application. In recent years cost of irrigation water and energy have increased, therefore any reduction in water pumped will result in corresponding decrease in per hectare energy demand of water application.

12. Previous studies of pumping energy requirement of irrigation have generally included only the on farm pumping. But as it is seen from the results of data collection from SZOLNOK TRVVV company the pumping energy requirement to bring water to a field is also considerable and therefore should be considered in calculating total pumping energy for irrigation. The computer Model No.1. presented here proved to be very useful in estimating total specific energy demand and energy cost of different irrigation systems for different water sources and energy sources, in a wide variety of operating conditions. Several input parameters like, total dynamic head /TDH/, depth of water application /DWA/, irrigation efficiency /IEF/, pumping efficiency /PEF/, specific fuel consumption /SFC/, ratio of night tariff to day /RNT/, water transport efficiency /TEF/ etc. can be varied within a desirable range to determine their effect on ultimate pumping energy and energy cost requirement of the system under consideration. Thus identifying those parameters which have significant influence on energy saving or demanding extra energy. The Model No.1. can be a useful tool for planners in estimating pumping energy demand on district, regional or national level with suitable modifications.

13. Selection of optimum size of pipe line sections are normally based on minimum cost design. With low energy cost it has been more economical to use smaller pipes than would be used for minimum energy design. Since energy prices are rapidly increasing, the procedure of selecting optimum pipe diameter should be modified. This has been proved by some of the examples illustrated in computer Model No.2. The pipe size designed as optimum on the basis of present pumping energy cost and pipe line investment cost may turn to be non-optimum due to excessive annual pumping energy cost during the later part of the system's expected life. Therefore future design should consider the predicted average energy price over the life of the system, and then calculate the optimum of pipe sections by adding it to annualized initial investment cost of the pipe section. Of course, in this situation the selection of optimum pipe size will be influenced by designers skill in predicting the average energy price. The procedure presented in Model No.2. helps in finding out modified optimum diameters of pipes for several predicted average energy prices, water flows, yearly operating hours, interest rates and system's life period. In the Model No.2. the energy consumed in manufacturing of pipe section has not been considered. However for developing of completed minimum energy design model manufacturing energy requirement should also be included.

14. The detailed stepwise procedure developed in computer Model No.3 proved to be very useful in comparing minimum investment and minimum energy designs of a pumping plant having one or more than one pumping units. From the analysis it was found that the specific investment cost of pump and pump appliances /PIC/, electrification /EIC/, water supply /WIC/, and maintenance, in general increases, while the pipe network investment cost /NIC/, in case of MIN INV design, slightly decreases with decrease of area irrigated by one pumping unit. The overall total investment cost /TIC/ incase of both MIN INV and MIN EN design increases if the given large area is divided into smaller pumping units. The yearly energy demand /YED/, influenced by the

quantity of water application /CUM/HA/, is lower for MIN EN design than MIN INV design. The MIN EN design required decreasing amount of specific energy /KWH/HA/ from larger to smaller pumping unit /eg; for A-variation, 1200 CUM/HA, from 450,0 KWH/HA to 418,4 KWH/HA for F-variation/. The MIN INV on the other hand, in general, required higher specific energy demand for splitted pumping units.

As regards the yearly total operation cost /YOC/, the MIN EN designs were found to be expensive for lower water applications i.e. for less than 1200 CUM/HA and energy price of 3,0 Ft/KWH, but for higher water applications i.e. 1200 CUM/HA and above, for energy prices of 3,0 and 6,0 FT/KWH, MIN EN designs equalled or in case substantially reduced the specific cost of irrigation.

Finally, it can be concluded that the specific investment cost of irrigation units of different sizes slightly increases with the decrease of area of one pumping unit and the optimum size is over 1500 hectars of irrigated land from one pumping unit. If the yearly utilization of irrigation pump exceeds 1500 CUM/HA and the specific cost of electricity is higher than 3,0 FT/KWH, the total yearly operation cost of irrigation plants of larger than 1500 HA comes smaller by adopting minimum energy design criteria. Expecting future trend of considerable increase of electric energy price and higher water applications, in future irrigation pumping plant designs, along with minimum investment cost design the minimum energy demanding design should also be worked out and only then the optimum solution should be finalized.

6. NEW SCIENTIFIC RESULTS

The most important results of executed scientific programme on the very new field of agricultural engineering research called - irrigation energy economy, can be summarized within two groups of issues, having different characteristics, i.e. the evaluation results of data collection and field experiments, the new scientific results of system models.

As regards the primary results of my own investigations, based mainly on data collection and technical measurements of electrically operated, installed sprinkler irrigation pumping units, I would like to stress on the following new ascertainments, which contribute for extending the scientific knowledge on the field of irrigation energy economy.

1/ The five years' average electric energy requirement of examined six sprinkler irrigation units, covering 7456 ha of land, proved to be $0,29 \text{ kWh/m}^3$ and 314 kWh/ha , and changed between comparatively narrow limits $0,23 - 0,32 \text{ kWh/m}^3$ and $280 - 372 \text{ kWh/ha}$, while the average specific energy cost of irrigation was found as $0,48 \text{ Ft/m}^3$ and 425 Ft/ha and $1,45 \text{ Ft/kWh}$. All these three energy cost parameters varied within considerably large limits $0,28 - 0,85 \text{ Ft/m}^3$, $330 - 509 \text{ Ft/ha}$ and $0.87 - 2,25 \text{ Ft/kWh}$, parallel with an increasing tendency, caused by the growth of energy tariffs, in general.

2/ The experienced largest value of specific energy cost parameters, belonging generally to the lowest level of water utilization, turned out to be extremely high /during several months $2,50 - 5,30 \text{ Ft/m}^3$ and $5,50 - 8,60 \text{ Ft/kWh}$ /, which resulted in significant increase of irrigation water supplying cost for water management company and consequently reducing the profitability of irrigation and lowering the interest of agricultural companies for further increase of their water demand.

3/ The discovered lowest energy cost parameters /0,26 - 0,30 Ft/m³ and 0,85 - 1,00 Ft/kWh/ at certain pumping units were always belong to the high values of yearly water consumption /1,5 - 2,5 million m³/year/, however they were also influenced, partly, by favourable values of specific pumping energy requirement /0,20 - 0,25 kWh/m³/.

4/ The daily averages of water pumped and the energy used by individual irrigation units, as it is unsophisticated in usual irrigation practice, greatly changes from day to day /2486 - 25047 m³/day and 1123 - 6482 kWh/day/, while the pumping unit efficiency factor varied between 50,8 - 67,8 % on the randomly selected days, giving an average value of 61,6 % for the whole establishment.

5/ The installed total pumping capacity at the examined irrigation units was substantially overcalculated. The yearly utilization of nominal water discharge capacity of pumps was very low /4,4 - 35,5 %/, and in most cases even the actually planned water demand was utilized in a small degree /17,6 - 54,8 %/. As the electric power was contracted for the total installed capacity, the utilization of electric power was also very low, and consequently in these cases the average cost of electricity proved to be undesirably high.

The new scientific results of my research activities based mainly on field experiments and reached with the help of completion of computer modelling and analysis could be summarized as follows.

1/ Making use of computer program No.1. the specific energy demand and energy cost of irrigation carried out by different energy and water sources, as well as with various irrigation techniques, and influenced by great number of other factors, was determined for large number of variations. The concrete energy and energy cost per hectare was computed for different basic variations and analysing the results I have established

that the most energy intensive way of irrigation is the portable sprinkler one. Among the given conditions the installed sprinkler irrigation needs slightly fewer energy /694,4 kWh/ha or 168,7 kg/ha/ compared to portable method /741,6 kWh/ha or 179,9 kg/ha/, for 1260 m³/ha water application, with primary lifting. The direct energy cost of installed irrigation was 1063 Ft/ha and 1687 Ft/ha, while for portable irrigation 1135 Ft/ha and 1800 Ft/ha for electric and diesel operated pumps, respectively, on the basis of energy price level in 1980. The less energy demanding drip irrigation method requires only 106,5 kWh/ha electricity or 26,3 kg/ha diesel oil among the same conditions. The computer model is suitable to determine the energy cost relationships for any practical situations, as a function of 25 different parameters and to print out the deviation from the desired basic values.

2/ The adoption of computer program No.2. have made it possible to determine the effect of energy price increasing onto the change of optimal irrigation pipe diameter of installed sprinkler irrigation systems. Restricting the analysis only to the cost of tube sections and energy demand necessary for transporting water through them, I have defined the optimum pipe diameter for 5 different yearly operation hours and 10 different water discharge values. It was established that while the energy price increases from 0,30 Ft/kWh /night tariff in 1979/ up to 6,00 Ft/kWh /present peak tariff with low utilization/ the optimum pipe diameter changes at least once, sometimes twice. Taking into consideration the steady increase of cost of energy over the life period of installed irrigation systems, in the future, the designing of irrigation systems should be based on changing energy price instead of the present procedure, where the energy price is taken as constant, with a very low value.

3/ On the basis of the analysis and computer programme No.3. I have established that the specific investment costs of irrigation units of different sizes slightly increases

with the unit size of one pumping plant and the optimum size is around 1500 hectares of irrigated land. The yearly operation cost of irrigation units of various size also depends upon their irrigated area /e.g. for 1200 CUM/HA water utilization starts from 7741 FT/HA and increase up to 9913 FT/HA, if the pipe investment cost is at minimum and changes from 7600 FT/HA to 11112 FT/HA, if the energy demand is at its minimum value/. If the yearly utilization of irrigation pump exceeds 1200 CUM/HA and the specific cost of electricity is higher than 3,0 FT/KWH, the total yearly operation cost of irrigation plants of larger than 1500 HA comes smaller if the minimum energy design criteria is applied. As the experienced critical parameters are not very far from the present commercial situations. I have to propose that the applied optimum criteria should be re-evaluated.

Finally, as a practical adoption of the results of my research work, I would like to ascertain the following:

- full utilization of night hours operation, ensuring maximum possible utilization of installed pumping capacity, and contracted electric power would further reduce the specific electric energy cost of irrigation by some 40-45 percent.
- improving water utilization efficiency at field level so as to apply only desired amount of water by further extending of scientific water management techniques, some 20 - 25 percent possible reduction of specific energy demand is possible.
- for future installations of semi-permanent sprinkler units, some suitable modification in the basic designing criteria concerning selection of total installed pumping capacity, optimum pipe diameters for the pipe network, and optimum size of land to be irrigated is suggested. At the same time development of instrumentation for laterals for steady checking and control of actual water application should be given due consideration.

7. SUMMARY

In the modern world we are facing an increasing shortage of food, energy, and water, Food shortage can be eliminated by development of irrigated plant production, however it needs both increasing amount of water and energy. For longterm irrigation development, the availability of water, investment funds and growing cost of energy are the basic limiting factors. Many irrigationists have been motivated to develop and operate irrigation systems to improve water utilization, but until recently energy conservation was not a major consideration. For solving this contradiction for creating the necessary conditions for harmonious progress in this field is an important part of national development policy. Consequently, a new line of irrigation research activity has been developed, which is concentrated to the energy and energy cost relationships of irrigation, and finding out possible ways of energy savings. The energy and energy cost analysis of irrigation includes technical, agronomical and economical aspects, too, thus the research programme carried out on this field should be an interdisciplinary one.

According to my estimation, the energy consumption exclusively for irrigation purposes during the last few years in Hungary varied between 20 to 30 million kWh, and 30 to 40 thousand tons of diesel oil per year. Thus irrigation energy consumption even nowadays is significant in total energy demand of agricultural production, and this share will grow in future.

The most important objectives of my research programme are;

- to carryout pertinent field experiments in large scale semi-permanent sprinkler irrigation units, and
- to develop pumping energy system models for determination of basic relationships.

The general methodology followed during the course of research programme consists of;

- collection of energetical data of irrigation, execution of longterm and short-term field experiments, and development of computer models.

The experiment site belongs to TISZA-II irrigation project in the middle-eastern part of Hungary. For the sake of carrying out detailed and extensive energetic studies and related field experiments, the most up-to-date large scale semi-permanent sprinkler irrigation plants established under NAGYKUNSAAG-XII Subsection in MEZŐHEK-TISZAFOLDVÁR districts were selected.

The total overall energy consumption of TRVVV SZOLNOK Company from the year 1974 onwards, and the specific energy and water application of each of the pumping unit of MEZŐHEK-TISZAFOLDVÁR irrigation plants were collected from 1976 to 1980 years. Further going more and more into the technical details of irrigation energy demand implications during 1979 and 1980 years' irrigation seasons, collection of monthly, weekly, and daily energy and water consumption parameters were organized.

On the basis of data collection, field experiments, and Model analysis the results obtained can be summarized as follows;

- the overall average specific energy consumption to supply water from source upto field and to distribute the water over the field, was found to change between 310 to 487 kWh/m³ and 54 to 112 kg/ha.

- the five years average electric energy requirement of the examined six sprinkler irrigation units covering 7456 hectares of land proved to be 0,29 kWh/m³ and 314 kWh/ha, and changed between comparatively narrow limits. The average specific energy costs of irrigation were found as - 0,48 Ft/m³, 425 Ft/ha, and 1,45 Ft/kWh. All these three energy cost parameters varied within con-

siderably large limits with an increasing tendency caused by the growth of energy tariff in general.

- it was observed that the lower specific energy cost values generally belong to higher yearly water applications, but it may be 3 to 4 times higher than the normal values if the utilization factor drops down by 20 to 25 percent.

- the daily average of water pumped and the energy used by individual pumping units greatly changed from day to day i.e. from 2400 to 25000 m³/day, and from 1100 to 6500 kWh/day, giving a very wide range of specific energy demand values i.e. 0,13 to 0,65 kWh/m³. It was observed that when the average amount of water pumped is more than 12000 m³/day, specific energy consumption values were substantially low. In general it was found that amount of water pumped has inverse relationship with the specific energy demand.

- the pumping unit efficiency varied between 50 to 68 %, giving an average value of 62 %. The specific energy consumption may be as much as 20 to 88 % higher in case of throttled operation than that of full hydrant discharge.

- the objective of Model No.1 is to determine the total specific pumping energy demand and energy cost of different irrigation systems and water sources in a wide variety of operating conditions. From the analysis the energy demand descending order of irrigation system can be given as; portable sprinkler, installed sprinkler, subsurface, surface, and drip. The model enables to vary a desired input parameter within the reasonable range to know its effect on energy demand and energy cost requirement.

- the objective of Model No.2 is to determine the effect of escalating energy prices onto the selection of optimum irrigation pipe diameter. For the assumed 5 different yearly operation hours and 10 different water discharges it was found that when the energy prices increases from 0,30 Ft/kWh to 6,0 Ft/kWh, the optimum pipe diameter changes at least once, some time twice.

Thus, the future designs should be based on changing energy price concept, instead of the present procedure where the energy price is taken as constant over the life period of the installation.

- the objective of Model No.3 is to determine the optimum land size of irrigation unit, and to compare minimum investment design with minimum energy design. From the analysis it was observed that the specific investment cost of irrigation unit of different sizes slightly decreases with the decrease of area of one pumping unit in case of MIN.INV. design, while it increases in case of MIN.EN. design. On the other hand, if the yearly utilization of irrigation water exceeds 1200 cum/ha and the specific cost of electricity is higher than 3,0 Ft/kWh, the total yearly operation cost of irrigation plants of larger than 1500 hectares comes smaller by adopting minimum energy design criteria.

Finally, as a conclusion I may stress on the following two most important new scientific findings of my research work;

- from the analysis of long-term and short-term field experiments, I conclude that in the examined sprinkler irrigation units the average specific energy demands are low, but the specific energy costs, in general, are undesirably high, and here lies the major possibility of practically adopting the scientific results of my research work.

- presented three system models dealing with energy aspects of irrigation are new and especially the formation of series of equation for development of models is a novelty in the professional literature. The Model No.1 is useful in determining the total specific pumping energy demand and cost of irrigation methods for any practical situation as a function of 25 different parameters. The Model No. 2 is helpful in optimizing irrigation pipe section diameters based on increasing energy prices for future installations. The utility of Model No.3 lies in optimizing irrigation land size on the basis of minimum investment cost and minimum energy design.

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A P P E N D I X

Appendix 1.1

Total irrigation capacity and the percentage
of different irrigation methods

Year	Total culti- vated land 10 ³ ha	Irrigati- on capacity 10 ³ ha	Technically supplied area			
			Total ha	Surface %	Subsur- face %	Pipe-line %
1960	5703,2	144,7	...	...	...	...
1965	5649,7	368,9	149,3	77,1	4,2	18,3
1970	5593,8	458,0	179,5	68,1	5,8	25,8
1971	5578,3	464,0	179,0	68,1	5,0	26,3
1972	5565,3	485,0	179,8	65,3	5,4	29,0
1973	5554,9	481,0	180,7	64,8	5,4	29,7
1974	5503,5	482,2	180,1	62,1	5,8	31,9
1975	5495,1	487,5	179,6	58,1	5,8	36,0
1976	5470,7	470,7	186,2	52,5	5,6	40,7
1977	5422,7	485,1	185,6	48,9	6,4	43,3
1978	5388,6	485,9	187,4	47,5	6,5	44,9
1979	5354,6	479,6	187,6	45,5	6,8	46,6

Source: Mezőgazdasági Statisztikai Zsebkönyv, 1965-1980.

Appendix 1.2

The irrigated land in Hungary and percentage of
various irrigation methods

Year	Total irrigated area 1000 ha	Percentage of total irrigated area			
		Sprinkler	Surface	Subsurface	Drip
1960	94,7	...	...	...	...
1965	99,8	...	...	...	...
1970	108,7	61,9	28,0	2,9	-
1971	204,9	72,6	25,9	1,5	-
1972	266,9	75,0	23,9	1,1	-
1973	310,5	77,5	20,1	2,4	-
1974	307,7	76,2	21,4	2,4	-
1975	155,5	68,4	27,4	4,2	-
1976	319,8	75,3	21,6	3,0	0,1
1977	297,7	77,0	18,9	3,9	0,1
1978	181,3	71,3	22,5	5,9	0,3
1979	251,8	78, 0	17,0	4,6	0,3

Source: Mezőgazdasági Statisztikai Zsebkönyv 1965-1980.

Appendix 1.3

Irrigation water utilization and
specific water application

Year	Irrigated land 10 ³ ha	Water used 10 ⁶ m ³	Water application mm			
			Total average	Arable land	Vine fruit	Pasture land
1970	108,7	389,1	358	400	127	154
1971	204,9	641,4	313	336	132	223
1972	266,9	679,0	254	270	125	175
1973	310,5	796,2	256	276	131	190
1974	307,7	676,0	220	243	117	158
1975	155,5	486,6	313	384	89	135
1976	319,8	793,6	248	276	115	171
1977	297,7	746,2	251	284	118	160
1978	181,3	496,2	274	324	98	162
1979	251,8	553,9	220	251	151	109

Source: Mezőgazdasági Statisztikai Zsebkönyv 1965-1980.

Appendix 1.4

The irrigation water utilization of different
pumped irrigation methods
/million m³/

Year	<u>The share of water utilization</u>						<u>Total</u>	
	<u>Sprinkler</u>		<u>Surface</u>		<u>Subsurface</u>		<u>electr. diesel</u>	
	elec.	diesel	elec.	diesel	elec.	diesel	elec.	diesel
1970	17,0	133,4	20,3	70,1	-	1,8	37,4	207,7
1971	31,6	266,0	20,3	158,7	-	1,8	52,0	429,3
1972	39,8	359,8	19,8	173,4	-	1,8	59,7	537,4
1973	48,2	433,2	19,8	169,7	-	1,8	67,9	607,4
1974	51,0	418,0	19,8	172,6	-	1,8	70,9	595,1
1975	64,0	483,6	15,8	228,0	-	1,5	48,7	437,9
1976	72,0	462,7	14,9	221,3	-	1,5	79,4	714,8
1977	76,8	491,2	21,8	234,0	-	1,5	74,6	671,6
1978	80,0	505,6	29,8	243,8	-	1,5	49,6	446,6
1979	92,8	523,2	29,8	257,8	-	1,5	55,4	498,5

From: 1975. calculated water demand

Source: Vizgazdálkodás távlati energiaigénye, VGI, 1977.

Appendix 1.5

The electric and diesel oil energy
utilization of irrigation in Hungary

Year	<u>The share of energy utilization</u>						Total	
	<u>Sprinkler</u>		<u>Surface</u>		<u>Subsurface</u>			
	electr.	diesel	electr.	diesel	electr.	diesel	electr.	diesel
1970	5,15	12,23	0,61	1,01	-	0,16	5,79	13,27
1971	9,58	24,63	0,61	2,22	-	0,16	10,22	26,88
1972	12,02	32,92	0,60	2,41	-	0,11	12,65	35,36
1973	14,60	39,60	0,60	2,34	-	0,16	15,22	41,98
1974	15,46	38,31	0,60	2,36	-	0,11	16,09	40,71
1975	19,39	44,34	0,48	2,09	-	0,14	15,2	30,65
1976	21,81	42,42	0,45	1,73	-	0,14	26,2	49,99
1977	23,27	45,03	0,67	2,14	-	0,14	28,1	47,01
1978	24,24	46,35	0,91	2,24	-	0,14	19,5	31,26
1979	25,12	47,96	0,91	2,36	-	0,14	20,5	34,89

Electric energy: in million kWh

Diesel oil: in thousand tons

Source: Vizgazdálkodás távlati energiaigénye, VGI, 1977.

Appendix 1.6

On-farm irrigation development in India
/in thousand Nos./

Period	Dug-wells	Private shallow tubewells	Public deep tubewells	Electric pump-sets	Diesel pump-sets
1950-1951	3860	3	2,4	21	66
1960-1961	4560	20	8,9	200	230
1968-1969	6110	360	14,7	1090	720
1973-1974	6700	1140	22,0	2430	1750
1977-1978	7426	1700	30,0	3300	2350
1979-1980	12000	4000	60,0	12000	5000

Source: Yojana, 1980. No.14, 15.

Appendix 2.1

Total energy inputs of various irrigation systems /19/ /in Mcal/

Irrigation	Installation	Pumping	Ratio of in- stallation per pumping	Labour	Total
Surface without runoff recovery	255,0	87,0	2,93	1,2	343,2
Surface with runoff recovery	444,5	118,6	3,75	0,7	563,9
Solide-set sprinkler irrigation	1517,4	1902,6	0,80	1,0	3419,8
Permanent sprinkler irrigation	1219,6	1902,6	0,64	0,3	3122,6
Hand moved sprinkler irrigation	394,6	1986,6	0,20	11,9	2393,2
Sid-roll sprinkler irrigation	494,9	1986,6	0,25	5,9	2488,5
Center-pivot sprinkler irrigation	959,9	2134,9	0,45	0,3	3095,2
Traveller sprinkler irrigation	713,8	3877,0	0,18	1,0	4591,1
Trickle irrigation	1310,9	1156,4	1,13	0,3	2467,5
Water demand 915 mm; pumping lift: 0 m; 1 Mcal = 4,19 MJ.					

Appendix 2.2

Irrigation water norms for typical crop groups /25/ /in m³/h, year/

Crop group	Sprinkler irrigation				Surface ir- rigation
	Climatic zones				
	I.	II.	III.	IV.	
Arable crops	2400	2000	1200	600	3000-2400
Grains	600	600	400	-	2400-2000
Vegetables	4000	3200	2000	1200	7200-5600
Vines, orchards	3200	2500	1600	-	4500-3600
Fodders	2500	2400	2400	-	5600-4800
Pastures	2500	2400	2400	-	5000-3600
Rice	-	-	-	-	11000-27000

Nominal capacity of irrigation pumping plants /26/ /in liter/s, ha/

	Net water demand		Gross water demand	
	surface	sprinkler	surface	sprinkler
Arable land	0,56	0,28	0,70	0,35
Vegetable	0,70	0,47	0,87	0,59
Orchard	0,70	0,33	0,87	0,42
Vines	0,70	0,33	0,87	0,42
Pastures	0,40	0,38	0,50	0,36
Rice	1,44	-	1,80	-
Others	0,40	0,24	0,50	0,31

Appendix 2.3

System efficiency and energy requirement for
different irrigation methods /9/

Irrigation system	System efficiency %	Dynamic head m	Energy requirement kWh/m ³
<u>Low lift /0-27,4 m/</u>			
- Surface without runoff use	50	1,8	0,06
- Surface with runoff use	65	3,7	0,10
- Auto-surface with runoff use	85	5,5	0,11
- Gated surface with runoff use	80	7,3	0,16
- Trickle irrigation	90	14,0	0,27
<u>Medium lift /27,4-53,3 m/</u>			
- Low pressure sprinkler center pivot	80	35,0	0,76
- Solid set sprinkler hand moved, side-roll	70	30,5	0,75
<u>High lift /above 53,3 m/</u>			
- High pressure sprinkler	80	53,4	1,15
- Travelling sprinkler Big gun	70	91,5	2,24

Applied water and consumed energy for various
irrigation systems /32/

Irrigation system	Water m ³ /ha	Energy kWh/ha	Specific energy kWh/m ³
Center-pivot	6098	2623	0,43
Hand move	7623	2699	0,35
Side-roll	2928	2928	0,37
Solid set	9453	3194	0,33
Gravity	11282	396	0,04

Appendix 2.4

Electric Energy requirement of different
irrigation systems /12/

Irrigation	Total head m	Energy requirement kWh/ha
Surface	2	30-50
Drip	8-10	100-200
Sub-surface	15-20	150-200
Sprinkler portable	45-55	450-500
Sprinkler semipermanent	45-55	550-650

Pumping efficiency: 70 %; yearly operating hours: 200-400,hrs
specific waterdemand: 2,0-2,5 l/s/ha.

Most important technical and economical data for NK-XII.

Appendix 3.1

Irrigation plants

	Unit	Mezőhek I.	Mezőhek II.	Mezőhek III.	T.földvár I.	T.földvár II.	Kungyalu I.	Total
Irrigated land	ha	1350	1488	1273	853	1122	1370	7456
Feeding canal	m	1200	40	1510	1870	1300	1320	7240
Main lines	No. m	4 10708	3 7476	4 6830	3 3596	4 6167	3 3620	21 38397
Submains	No. m	34 20844	21 23816	24 22364	12 14603	19 17216	11 20298	121 119141
Pumping units	No. l/s	4+2 800	4+2 840	4+2 800	2+2 425	4+2 532	3+2 660	21+12 4057
Planned waters	10 ³ m ³	1300	1700	2000	2400	2000	2000	11400
Investment cost				I-II-III		I-II.		
State mains	Ft			15481		11148	7129	33758
State service	Ft			86420		48651	37378	168449
Company	Ft			25851		11090	10686	46627
Total	Ft			127752		70889	51193	249834
Specific cost								
State mains	Ft/ha			24817		30278	29567	28221
and service	Ft/m			1388		1704	2140	1586
	Ft/l/s			52353		74074	77565	61581
Total pipe-length	m			92038		41582	23918	157538

Appendix 3.2

Most important technical characteristics of sprinkler irrigation laterals

Type	Hydrant pressure		Water discharge l/s	Lateral Pipe dia- meter		S p r i n k l e r s				Area		Covered total mxm	Water- appli. rate mm/h	
	m			m	mm	Type	Dia- meter mm	Dis- charge l/s	No.	unit mxm				
<u>Toeing</u>														
AIVSZ-87	35		14,1	240	87	TISZA-II	8,6	1,41	10	24x24	24x240	8,8		
ALVASZ-130	40		28,8	240	130	T-45	12/7	3,60	8	30x36	36x240	12,0		
VMV-90	35		15,5	240	80	TISZA-II	8,6	1,41	11	24x24	24x264	8,8		
<u>Rolling</u>														
OBA, OBM	35		14,1	216	130	TISZA-II	8,6	1,41	10	24x24	24x216	8,0		
GO-240	35		25,2	216	130	T-45	12/7	3,60	7	36x36	36x252	12,0		
GO-252	35		29,6	267	130	TISZA-III	13,0	3,71	8	36x36	36x288	10,3		
VOLZSANKA	35		30,0	390	125	VOLZS	7,0	0,94	32	18x12,6	12x576	14,9		
JÜTTERBOG	40		18,0	290	133	V-64	12,0	2,00	9	24x24	24x216	12,5		
<u>Wounding</u>														
RAIN-ROLL-75	35		14,0	264	63	TISZA-II	8,6	1,41	10	24x24	24x240	8,75		
CSSZV-90	40													
SCHLEBUSCH	35		13,2	234	58	L-64	7,0	1,01	13	24x18	24x234	7,80		
<u>Rotating boom</u>														
KF-120	45		23,2	79					16+2	96x96		11,86		
CK-100	60		18,0	76					12+2	80x80		10,0		
BOOM-O-RAIN	55		27,0	86					16+1	96x96		6,3		
<u>Travelling</u>														
ROLLOMAT	60		12,5	270	90	ZN-30	22,0	12,5	1	..x70	70x300	46,0		
REGENGIGANT	60		35,0	200	100	SR-35	33,0	35,0	1+2	..x103		104,0		
<u>Self propelled</u>														
FREGAT	50-65		30-100	277-455	178-152	-	-	-	30-50	-	30-74 ha	12-18		

Appendix 3.3

Overall irrigation characteristics of Szolnok TRVVV Company

Year	<u>Irrigation area</u>		Water consumed	Energy consumed	Energy cost	Specific energy	
	Installed	Irrigated	1000m ³	1000 kWh	1000 Ft	kWh/m ³	utilization kWh/ha
	ha	ha					
<u>Electric operated</u>							
1974	22708	28777	129483	8975	5803	0,069	311,9
1975	23322	17327	114614	6310	4743	0,055	364,2
1976	24208	29060	137490	12409	10682	0,090	427,0
1977	23953	26891	139166	11495	9772	0,082	427,5
1978	26720	13747	106719	6808	9320	0,063	486,9
1979			204509	9797		0,048	
<u>Diesel operated</u>							
1974	10367	10425	33402	t 1158	5416	g/m ³ 34,67	kg/ha 111,1
1975	16605	7125	33633	571	2670	16,98	80,1
1976	19323	19991	60956	1086	5844	17,82	54,3
1977	18225	14526	48877	845	4547	17,29	58,2
1978	19367	10580	25772	578	3115	22,43	54,6
1979							

Appendix 3.4

Energy consumption and water discharge

Szolnok, TRVVV - 1979.

ELECTRIC OPERATED 1.

Place	No. and types of pumps	Water, 1000 m ³	Operation hours	Energy kWh	Specific kWh/m ³
<u>Primary lifting</u>					
<u>pumps</u>					
Tl. szavárkony I.	3xECSK-800	4043	1902	197233	0,0488
Tl. száorvény	3xVCSK-1200	38463	4567	786600	0,0204
Jászágatorok	20xECSK-800	18637	7056	464056	0,0249
Tl. szapusóka	4xECSK-800	2551	1174	88559	0,0347
Tl. zabecs	3xECSK-800	747	411	37260	0,0498
Tunyogmatolcs	2xECSK-800	448	235	21480	0,0479
Décs-Fazekaszug	10xECSK-800	20602	9207	681900	0,0331
Csánytelek	2xAGROFIL-500E	8217	3987	454882	0,0491
Levelény	2xECSK-800	1767	915	86760	
Algyó	4xAGRORIL-500E	5089	1936	205000	0,0403
Szarvas-Káka	3xCSV-500, 1000	46653	9407	685591	0,0147
Biharugra	2xCSVK-800	15831	4746	180480	0,0114
Total:	-	163048	45543	3889801	0,02385
<u>Secondary lifting</u>					
<u>pumps</u>					
NK-IV-1	10xECSK-800	3433	1267	74600	0,0217
NK-IV-1-3	2xAGROFLUS-500E	4511	1512	54241	0,0120
Kőtelek	3xAGROFLUS-500E	6979	2748	71217	0,0102
Tomörkény	3xELCSO-500	8158	4160	202153	0,0248
Total:	-	23081	9687	402211	0,0174

Energy consumption and water discharge

Szolnok, TRVVV - 1979.

ELECTRIC OPERATED 2.

Place	No. and types of pumps	Water 1000 m ³	Operation hours	Energy kWh	Specific kWh/m ³
<u>Sprinkler irrigation pumps</u>					
Mezőhek I.	2+4xUNS-150,250	1207	2920	402788	0,334
Mezőhek II.	2+4xUNS-150,250	1803	4963	544592	0,302
Mezőhek III.	2+4xUNS-150,250	1082	4242	317948	0,294
Tiszaaföldvár I.	2+2xUNS-150,250	1059	3112	307464	0,290
Tiszaaföldvár II.	2+3xUNS-150,250	994	2868	295324	0,297
Kungyalu I.	2+3xUNS-150,250	2347	5049	669822	0,285
Kerekdomb	1+5xTGV-60,250	2426	5545	507295	0,209
Kisújszállás	2+5xUFW-250	1948	4270	626053	0,321
Nagyhegyes	4xDAK-250	1423	2359	540308	0,379
Rakamaz	1+5xTGV-150,250	1181	2673	350636	0,297
Vencsellő	2+6xUSN-150,250	530	1084	198210	0,374
Hajdúnánás	2+3xMVD-250,350	920	3021	303200	0,329
Hajdúszovát	1+5xUFW-170,250	276	1126	110571	0,400
Szentes-Donát	2+5xUFW-150,250	1184	2385	330942	0,279
Total:	-	18.380	44.627	5,505.153	0,299

Appendix 3.6

Energy consumption and water discharge

DIESEL OPERATED 1.

Szolnok, TRVVV - 1979.

Place	No. and types of pumps	Water 3 1000 m	Operation hours	Energy kg	Specific g/m ³
<u>Primary lifting pumps</u>					
Oballa	6xAGROFIL-400D	5857	3793	47171	8,05
Kutrét	4xAGROFIL-500D	3194	2003	19222	6,02
Mezőtur	2xAGROFIL-500D	1086	746	6531	6,01
Tiszakécske	4xDCSK-800	3550	3260	32000	9,01
Tiszainoka	2xDCSK-800	1391	740	7733	5,56
Rákócziújfalú	4xTD-300	2661	3424	24318	9,14
NK-II. Ocsod	8xDCSK-800	18366	15528	151935	8,27
Tiszavárkony	4xPAJTÁS-VI.F	745	993	6707	9,00
Komlódtótfalu	2xDMO-300	522	352	2305	4,42
Ferencszállás	1xDMPPT-22	533	768	3871	7,00
Nagytóke	2xPAJTÁS-VI.F	836	1101	6753	8,08
Kurca	10xDCSK-800	15315	9859	82447	5,38
Vidraér	2xAGROFIL-400D	1937	1345	18529	9,57
Kőrosladány	6xDCSK-800	21433	9180	96025	4,48
Morgófok	4xDCSK-800	5891	4099	47021	7,98
Szeregyháza	4xDCSK-800	686	405	4656	6,79
Ecsegfalva	3xDMPPT-1	1295	1046	5708	4,41
Bokros	1xPAJTÁS-VI.F	443	615	3763	8,49
Total:		85761	59257	566695	6,61

Appendix 3.7

Energy consumption and water discharge

Szolnok, TRVVV - 1979

DIESEL OPERATED 2.

Place	No. and types of pumps	Water, 1000 m ³	Operation hours	Energy kg	Specific g/m ³
<u>Secondary lifting pumps</u>					
J-I-1	4xDCSK-800	5953	2566	20233	3,40
G-III	3xTO-300	2961	3813	32500	10,98
Mezőtúr	4xDMPT-11	1601	1277	6971	4,35
42.átemelő	3xDCSK-800	9034	7011	64168	7,10
Palotás	3xDCSK-800	3352	2766	21932	6,54
KFCS-25	1xPAJTÁS-VI.F	2130	3605	14563	6,84
Pálfo	1xPAJTÁS-VI.F	987	1743	5373	5,44
Derecske	3xDCSK-800	1507	1762	16185	10,74
Total:		27525	24443	181925	6,61
<u>Sprinkler irrigation pumps</u>					
Abádszalók	10xMA-350	617	4318	47714	77,33
Total:	-	617	4318	47714	77,33

Appendix 3.8

Concentrated sprinkler irrigation plants in Hungary built up during 1964-1977.

No.Place	Year	NWD l/s	TDH m	PPD kW	Water discharge l/s	
					Main pumps	Basic pumps
1. Kalocsa I.	1964	800	70	815	4x200	1x12
2. Kalocsa II.	1965	800	70	815	4x200	1x12
3. Balatonaliga	1965	360	120	655	4x90	1x12
4. Nagyhegyes	1965	700	76	860	4x175	2x22
5. Zalavár	1966	800	65	963	4x200	1x7+2x65
6. Alsónémedi	1967	600	65	763	3x200	1x7+2x65
7. Nagyszentjános	1978	600	55	763	3x200	1x7+2x65
8. Torokszent- miklós	1968	630	80	1017	5x126	1x10
9. Kerekdomb	1973	630	80	1017	5x126	1x10
10. Érsekhalma	1969	450	135	1074	4x112	2x16
11. Harta-Észak	1972	960	80	1234	6x160	2x10
12. Harta-Dél	1973	740	68	840	4x185	1x30
13. Kisujszállás	1972	1000	82	1305	5x200	2x45
14. Hajduszovát	1973	660	75	970	3x220	2x70+1x30
15. Kecskemét	1975	340	75	467	2x125	2x45+1x30
16. Rakamaz	1973	760	72	1215	4x190	1x125x1x45
17. Szabadszállás	1975	850	83	1465	5x170	1x125x1x45
18. Balatonfő	1973	700	88	1010	4x140	1x70x1x30
19. Szentés-Donát	1974	900	76	1360	5x180	2x45
20. Nemesnáádudvar	1974	465	100	750	3x125	2x45
21. Mezőhék I.	1975	784	80	1150	4x196	2x50
22. Mezőhék II.	1975	824	80	1150	4x206	2x50
23. Mezőhék III.	1976	728	80	1150	4x182	2x50
24. Tiszaaföldvár I.	1975	780	80	1150	4x195	2x50
25. Tiszaaföldvár II.	1976	560	80	900	3x182	2x50
26. Kungyalu I.	1977	560	84	900	3x186	2x50
27. Vencsellő	1977	972	80	1610	6x162	2x50
28. Szabad	1977	800	95	1150	2x350	2x50
29. Sió balpart	1977	720	85	980	2x300	2x60
Total:	-	20473	-	29498	-	-

Source: Roser, O.: Szivattyútelepek automatizálása, VIZDOK 1979.

Energy consumption and water discharge at Mezőhék-Tiszafoldvár irrigation plant

Year	Irrigated land ha	Water charge 1000 m ³	Water application m ³ /ha	Energy consump. kWh	Energy cost Ft	Specific energy consumption		Specific energy costs	
						kWh/ha	kWh/m ³	Ft/kWh	Ft/m ³
Mezőhék I. 1349 ha	1976	1066	1139	382800	396934	359,1	0,336	1,037	0,348
	1977	908	784	298400	292680	328,6	0,382	0,981	0,373
	1978	1101	643	210296	455320	191,2	0,327	2,165	0,708
	1979	1314	1441	394304	465313	300,1	0,274	1,180	0,323
	1980	1037	713	235128	380346	226,7	0,330	1,618	0,533
Mezőhék II. 1489 ha	1976	861	858	272000	283160	315,9	0,317	1,041	0,330
	1977	904	1089	352400	318930	389,8	0,324	0,905	0,293
	1978	465	298	101000	317111	217,2	0,339	3,140	1,064
	1979	1397	2205	544592	617017	399,8	0,247	1,133	0,280
	1980	656	473	140556	302723	214,3	0,297	2,154	0,640
Mezőhék III. 1273 ha	1976	1145	1744	525200	556945	418,7	0,301	1,060	0,319
	1977	759	909	284800	253271	375,2	0,313	0,889	0,279
	1978	899	718	212070	437103	235,9	0,295	2,061	0,609
	1979	1061	1361	313908	453635	295,0	0,229	1,445	0,333
	1980	686	351	101808	285080	148,4	0,287	2,800	0,812
Tiszafoldvár I. 853 ha	1976	826	1523	469600	482593	568,5	0,308	1,027	0,317
	1977	26	11	5200	6899	200,0	0,437	1,327	0,627
	1978	612	425	130492	224054	213,2	0,307	1,717	0,527
	1979	853	1539	309464	420042	492,4	0,201	1,357	0,273
	1980	395	398	86880	192394	220,0	0,218	2,214	0,483
Tiszafoldvár II. 1122 ha	1976	1076	1172	374548	399003	344,6	0,316	1,065	0,340
	1977	992	986	306800	264047	309,3	0,311	0,860	0,268
	1978	646	377	118372	317189	183,2	0,314	2,680	0,841
	1979	1000	1385	295322	485394	485,4	0,211	1,644	0,349
	1980	236	211	67872	257627	287,6	0,322	3,796	1,221
Kungyalu 1370 ha	1976	1370	1125	293484	369547	214,2	0,261	1,259	0,328
	1977	1122	1700	506000	419233	450,9	0,298	0,828	0,247
	1978	1012	1012	179376	387028	177,2	0,249	2,158	0,538
	1979	1370	2671	628020	683963	458,4	0,240	1,089	0,256
	1980	1001	1447	492072	624718	340,1	0,340	1,270	0,432

Seasonal characteristics of energy utilizationMEZŐHÉK I.

Month	Water 3 1000 m ³	Energy kWh	Energy cost Ft	Specific energy and cost	
				kWh/m ³	Ft/m ³
1978. IV.	140	49288	78411	0,352	0,56
V.	100	27876	58070	0,279	0,58
VI.	75	29492	76066	0,393	1,10
VII.	72	18800	57255	0,261	0,79
VIII.	153	59388	101901	0,388	0,67
IX.	103	25452	83617	0,247	0,81
Total:	643	210296	455320	0,327	0,71
1979. IV.	79	30704	44918	0,388	0,57
V.	182	60600	61309	0,333	0,34
VI.	568	115140	105242	0,203	0,19
VII.	146	33128	65639	0,227	0,50
VIII.	215	65044	86026	0,303	0,40
IX.	251	89688	102179	0,357	0,41
Total:	1441	394304	465313	0,274	0,32
1980. III.	12	2020	25334	0,168	2,11
IV.	179	38380	58723	0,214	0,33
V.	25	32724	53819	1,309	2,15
VI.	116	19392	40605	0,167	0,35
VII.	143	52116	69947	0,364	0,49
VIII.	165	56156	74352	0,340	0,45
IX.	73	34340	57566	0,470	0,79
Total:	713	235128	380346	0,330	0,53
					1,62

Seasonal characteristics of energy utilizationMEZŐHÉK II.

Month	Water 3 1000 m ³	Energy kWh	Energy cost Ft	Specific energy kWh/m ³	Specific energy and cost Ft/m ³	cost Ft/kWh
1978. IV.	39	16160	53363	0,414	1,37	3,30
V.	29	6464	42097	0,223	1,45	6,51
VI.	145	44440	72548	0,306	0,50	1,63
VII.	21	14140	45652	0,673	2,17	3,23
VIII.	31	7676	45837	0,248	1,48	5,97
IX.	33	12120	57614	0,367	1,75	4,75
Total:	298	101000	317111	0,339	1,06	3,14
1979. IV.	162	54944	93717	0,339	0,58	1,71
V.	317	95344	101943	0,301	0,32	1,07
VI.	1024	156348	135347	0,153	0,13	0,87
VII.	192	60196	83509	0,314	0,43	1,39
VIII.	253	74740	92317	0,295	0,36	1,24
IX.-X.	257	103020	110184	0,401	0,43	1,07
Total:	2205	544592	617017	0,247	0,28	1,13
1980. IV.	118	29088	76869	0,267	0,67	2,71
V.	10	8448	32774	0,845	3,28	3,88
VI.	-	-	24950	-	-	-
VII.	150	27856	48573	0,186	0,32	1,75
VIII.	188	61812	80531	0,329	0,43	1,30
IX.	7	13332	37027	1,905	5,29	2,78
Total:	473	140556	302723	0,297	0,64	2,15

Seasonal characteristics of energy utilization

MEZŐHÉK III.

Month	Water ³ 1000m	Energy kWh	Energy cost Ft	Specific energy and cost	
				kWh/m ³	Ft/kWh
1979. IV.	58	25452	64572	0,438	1,11
V.	55	8888	45509	0,161	0,83
VI.	16	4848	41908	0,303	2,62
VII.	21	6060	42073	0,288	2,00
VIII.	200	52116	92195	0,261	0,46
IX.-X.	368	114706	150846	0,311	0,41
Total:	718	212070	437103	0,295	0,61
1979. IV.	104	35956	62264	0,345	0,60
V.	189	54944	58520	0,291	0,31
VI.	614	89284	99625	0,145	0,16
VII.	47	26260	65197	0,558	1,39
VIII.	350	89688	98889	0,256	0,28
IX.	57	17776	69140	0,311	1,21
Total:	1361	313908	453635	0,230	0,33
1980. IV.	105	37976	90502	0,361	0,86
V.	7	7272	31807	1,039	4,54
VI.	6	4444	31598	0,740	5,27
VII.	173	44036	72374	0,254	0,42
VIII.	10	7676	34712	0,768	0,35
IX.	-	404	24087	-	-
Total:	351	101808	285080	0,290	0,81
					2,80

ÖNTÖZŐTELEPEK ÉS SZIVATTYÚK ENERGETIKAI ADATAI

Telephely: Mezőhék-I
 Időpont: 1979. Július hó
 Kitöltötte: Bod Péter

Nap	Szivattyú üzemőre számlálók állása						Villamos fogyasztásmérő			Víz mennyiség mérő állása
	1. Fősziv.	2. Fősziv.	3. Fősziv.	4. Fősziv.	1. Alapsz.	2. Alapsz.	I. Éjjel	II. Oszo	III.	
21	906,42	361,96	858,54	1080,07	1657,05	1001,45	659,01	144,02	2380,62	46926,3
22	906,42	361,96	858,54	1080,07	1657,05	1001,45	659,01	144,02	2380,62	46926,3
23	906,42	361,96	858,54	1080,07	1657,05	1001,45	659,01	144,02	2387,00	46926,3
24	929,89	361,96	858,54	1084,07	1662,27	1001,45	660,45	144,02	2398,25	47184,3
25	940,33	361,96	858,54	1084,07	1667,30	1001,45	661,20	144,02	2407,50	47334,0
26	956,76	361,96	858,54	1084,07	1674,09	1001,45	662,00	144,02	2417,04	47655,2
27	967,65	361,96	858,54	1084,07	1674,09	1001,45	662,65	144,02	2423,22	47808,7
28	973,61	361,96	858,54	1084,91	1674,89	1001,45	662,65	144,02	2427,00	47897,5
29	973,61	361,96	858,54	1084,91	1674,89	1004,45	662,65	144,02	2427,00	47897,5
30	974,44	362,11	858,54	1088,72	1683,74	1004,45	663,24	144,02	2432,90	48039,8

A szivattyú üzemőreszámlálók, a háromárszabású villamos fogyasztásmérők és a GAMMA víz mennyiség /m³/ számlálók állását mindennap déli 12 órkor kérjük leolvasni!

ÖNTÖZŐTELEPEK ÉS SZIVATTYÚK ENERGETIKAI ADATAI

Telephely: Mezőhétk-IIIdőpont: 1979. június 10Kitöltötte: István

Nap	Szivattyú üzemőre számlálók állása						Villamos fogyasztásmérő			Vízmenyiség mérő állása
	1. Főszív.	2. Főszív.	3. Főszív.	4. Főszív.	1. Alesz.	2. Alesz.	I. Éjjel	II. Csucs	III.	
1	703,41	723,34	584,81	964,89	2215,21	2226,34	451,5	45,7	1306,7	68785,3
2	703,41	747,08	592,95	964,89	2217,41	2229,01	457,4	45,7	1320,0	69338,3
3	703,41	753,07	607,39	964,89	2217,41	2229,01	462,1	45,7	1328,4	69705,0
4	703,41	760,80	607,39	964,89	2223,40	2235,00	463,5	45,7	1333,4	70018,6
5	703,41	767,13	627,70	964,89	2231,30	2242,52	468,8	45,7	1345,6	70505,1
6	703,41	774,50	645,70	964,89	2243,20	2250,50	474,9	45,7	1356,5	70988,2
7	703,41	787,77	667,66	964,89	2243,60	2250,12	480,5	45,7	1370,4	71558,1
8	703,41	811,60	672,90	964,89	2251,80	2256,60	486,0	45,7	1383,7	72159,9
9	703,41	853,	675,30	964,89	2257,10	2261,40	490,5	45,7	1395,3	72622,9
10	703,41	847,20	695,10	964,89	2272,50	2264,60	497,5	45,7	1410,0	73275,6

A szivattyú üzemőreszámlálók, a háromárszabású villamos fogyasztásmérők és a GAMMA vízmenyiség /m³/ számlálók állását mindennap déli 12 órkor kérjük leolvasni!

ÖNTÖZŐTELEPEK ÉS SZIVATTYUK ENERGETIKAI ADATAI

Telephely: Úiszasoldvár IIdőpont: 1979. június 16Kitöltötte: Ferenc

Nap	Szivattyú üzemóra számlálók állása						Villemos fogyasztásmérő			Víz mennyiség mérő állása
	1. Fősziv.	2. Fősziv.	3. Fősziv.	4. Fősziv.	1. Alapsz.	2. Alapsz.	I. Éjjel	II. Csucs	III.	
1	1694,97	4,16	4,16	1675,45	1461,83	1290,26	306,31	59,5	660,64	53307,8
2	1691,35	4,16	4,16	1682,86	1476,82	1298,95	309,50	59,5	667,91	53932,4
3	1691,35	4,16	4,16	1688,78	1483,81	1309,70	312,42	59,5	671,81	54343,8
4	1691,35	4,16	4,16	1696,01	1484,51	1310,41	313,40	59,5	674,80	54846,7
5	1691,58	4,16	4,16	1717,77	1487,57	1312,70	318,17	59,5	681,73	55672,3
6	1691,58	4,16	4,16	1740,67	1487,57	1312,70	323,00	59,5	689,50	56564,7
7	1691,58	4,16	4,16	1743,02	1509,05	1331,19	325,09	59,5	694,51	57012,7
8	1691,58	4,16	4,16	1743,02	1528,57	1337,74	327,45	59,5	697,30	57228,8
9	1691,58	4,16	4,16	1743,13	1528,57	1337,56	327,45	59,5	697,43	58267,4
10	1691,58	4,16	4,16	1743,13	1528,57	1337,56	328,85	59,5	697,43	58267,4

A szivattyú üzemóraszámlálók, a háromárszabású villemos fogyasztásmérők és a GAMMA víz mennyiség /m³/ számlálók állását mindennap déli 12 órakor kérjük leolvasni!

ÖNTÖZŐTELEPEK ÉS SZIVATTYUK ENERGETIKAI ADATAI

Telephely: Liszaföldvár IIIdőpont: 1979. Június hóKitöltötte: Sándor

Nap	Szivattyu üzemóra számlálók állása						Villamos fogyasztásmérő			Víz mennyiség mérő állása
	1. Fősziv.	2. Fősziv.	3. Fősziv.	4. Fősziv.	1. Alapsz.	2. Alapsz.	I. Éjjel	II. Osuch	III.	
1	610,40	1237,86	7,67	1159,67	2242,47	2245,03	511,3	71,6	1047,7	11971,8
2	610,40	1237,86	7,67	1159,67	2266,42	2245,03	512,8	71,6	1050,2	11971,8
3	610,40	1237,86	7,67	1159,67	2284,34	2245,03	514,3	71,6	1051,8	11971,8
4	610,40	1237,86	7,67	1159,67	2290,22	2245,03	514,3	71,6	1052,3	11971,8
5	610,40	1237,86	7,67	1159,67	2314,18	2246,98	515,7	71,6	1055,6	11980,3
6	610,40	1237,86	7,67	1159,67	2332,41	2258,27	517,6	71,6	1060,5	12040,6
7	610,40	1265,00	7,67	1159,67	2346,00	2259,00	523,0	71,6	1074,7	12600,1
8	610,40	1291,61	7,67	1159,67	2364,91	2267,60	528,7	71,6	1083,3	13162,4
9	610,40	1313,00	7,67	1159,67	2377,48	2278,26	533,7	71,6	1092,2	13423,5
10	610,40	1336,46	7,67	1159,67	2390,63	2289,91	538,1	71,6	1102,8	13916,4

A szivattyu üzemóraszámlálók, a háromárszabású villamos fogyasztásmérők és a GAMMA víz mennyiség /m³/ számlálók állását mindennap déli 12 órakor kérjük leolvasni!

ÖNTÖZŐTELEPEK ÉS SZIVATTYUK ENERGETIKAI ADATAI

Telephely: Kungyalu IIdőpont: 1979. Június hóKitöltötte: András

Nap	Szivattyú üzemóra számlálók állása					Villamos fogyasztásmérő				Víz mennyiség mérő állása
	1. Főszív.	2. Főszív.	3. Főszív.	4. Főszív.	1. Alapsz.	2. Alapsz.	I. Éjjel	II. Csucs	III.	
21	942,01	1032,49	2335,84	—	537,7	1993,23	2719,2	864,9	6173,7	23953,4
22	955,17	1032,49	2335,84	—	537,7	1903,00	2721,3	864,9	6182,0	24406,5
23	955,17	1032,49	2335,84	—	537,7	1903,00	2721,3	864,9	6182,0	24406,5
24	955,17	1032,49	2335,84	—	537,7	1903,00	2721,3	864,9	6182,0	24406,5
25	966,95	1032,49	2335,84	—	537,7	1914,73	2721,8	864,9	6191,8	24910,8
26	980,30	1038,01	2335,87	—	537,7	1923,55	2723,9	864,9	6202,5	25440,1
27	914,12	1049,35	2335,87	—	537,7	1926,16	2726,3	864,9	6214,5	26015,0
28	1008,16	1055,46	2343,82	—	537,7	1927,62	2729,5	864,9	6227,1	26622,4
29	1014,91	1061,51	2355,09	—	537,7	1931,12	2732,0	864,9	6238,6	27153,4
30	1014,91	1075,18	2366,98	—	537,7	1931,65	2734,9	864,9	6249,8	27770,0

A szivattyú üzemóraszámlálók, a háromárszebasu villemos fogyasztásmérők és a GAMMA víz mennyiség /m³/ számlálók állását mindennap déli 12 órakor kérjük leolvasni!

ÖNTÖZŐTELEPEK ÉS SZIVATTYUK ENERGETIKAI ADATAI

Telephely: Mezőhék IIdőpont: 1980. AugusztóKitöltő: Bod Péter

Nap	Szivattyu üzemőre számlálók állása							Villemos fogyasztásmérő			Víz mennyiség mérő állása
	1. Főszív.	2. Főszív.	3. Főszív.	4. Főszív.	1. Alepsz.	2. Alepsz.	I. Éjjel	II. Csucs	III.		
11	1069,27	363,02	1081,80	1136,10	2572,65	1103,09	43,50	—	129,8	79715,8	
12	1069,27	363,02	1093,09	1136,10	2575,32	1103,09	44,55	—	136,0	79926,5	
13	1069,27	363,02	1093,09	1136,10	2575,32	1103,09	44,55	—	136,0	79926,5	
14	1069,27	363,02	1119,15	1136,10	2576,91	1103,18	46,55	—	149,10	80418,3	
15	1069,27	363,02	1129,45	1136,10	2581,73	1103,19	48,15	—	154,9	80655,2	
16	1069,27	363,02	1135,28	1136,21	2583,30	1103,19	48,70	—	157,9	80755,0	
17	1069,27	363,02	1148,56	1136,21	2583,30	1103,19	48,70	—	157,9	80955,8	
18	1069,27	363,02	1148,56	1136,21	2583,79	1103,20	49,65	—	164,4	80987,8	
19	1069,27	363,02	1162,32	1136,21	2583,90	1103,20	50,75	—	171,10	81229,5	
20	1069,27	363,02	1162,32	1136,21	2583,90	1103,20	50,81	—	171,15	81229,5	

A szivattyu üzemőrszámlálók, a háromárszabásu villemos fogyasztásmérők és a GAMMA víz mennyiség /m³/ számlálók állását mindennap déli 12 órakor kérjük leolvasni!

ÖNTÖZŐTELEPEK ÉS SZIVATTYUK ENERGETIKAI ADATAI

Telephely: **Mezőhegy II**Időpont: 1980. **Augusztus** hóKitöltötte: **József**

Nap	Szivattyú üzemóra számlálók állása						Villemos fogyasztásmérő			Víz mennyiség mérő állása
	1. Fősziv.	2. Fősziv.	3. Fősziv.	4. Fősziv.	1. Alapsz.	2. Alapsz.	I. Éjjel	II. Csucs	III.	
11	1138,2	896,3	1007,2	965,9	3717,0	3445,0	79,0	—	455,3	20594,1
12	1138,2	896,3	1019,3	965,9	3727,5	3758,8	80,2	—	463,7	21504,6
13	1138,2	896,3	1028,4	965,9	3734,2	3765,5	81,6	—	469,2	22319,6
14	1138,2	896,3	1030,7	965,9	3744,8	3767,2	82,7	—	476,1	23170,6
15	1138,2	896,3	1042,6	965,9	3754,1	3773,1	83,9	—	482,7	24016,3
16	1138,2	896,3	1051,4	965,9	3760,3	3779,3	84,7	—	487,8	24752,9
17	1138,2	896,3	1051,4	965,9	3772,3	3780,2	85,0	—	489,7	25339,9
18	1138,2	896,3	1060,5	965,9	3775,8	3783,9	85,5	—	494,6	26060,2
19	1138,2	896,3	1071,0	965,9	3786,0	3794,0	86,4	—	502,4	26985,1
20	1138,2	896,3	1071,0	965,9	3786,8	3794,8	86,4	—	502,7	27581,2

A szivattyú üzemóraszámlálók, a háromárszabású villemos fogyasztásmérők és a GAMMA víz mennyiség /m³/ számlálók állását mindennap déli 12 órakor kérjük leolvasni!

Appendix 3.20

Energy consumption and water discharge
data of sprinkler irrigation units
1979.

MEZŐHÉK I.

Date	Pumps operated	Electric energy		Water discharge		Specific energy ₃ kWh/m ³
		Meter	kWh	Meter	m ³	
JUNE 6	B1+M4	9,34	3736	198,85	7954	0,47
7	M1+M4	11,40	4560	237,30	9492	0,48
8	B1+M1+M4	12,02	4808	259,40	10376	0,46
9	M4	8,12	3248	317,10	12684	0,26
10	B1+M1+M4	12,71	5084	216,65	8666	0,59
11	B1+M1	6,35	2540	113,17	4527	0,56
12	B1+M1+M4	12,00	4800	276,08	11043	0,43
21	M4	10,96	4384	253,10	10124	0,43
23	M4	7,84	3136	351,06	14042	0,22
29	B1+M4	5,19	2076	83,10	3324	0,62
30	M4	5,16	2064	84,20	3368	0,61
Average per day:		-	3676	-	8691	0,47
JULY 1	M1	0,79	316	10,90	436	0,72
2	M4	4,10	1640	86,90	3476	0,47
19	B1+M4	7,21	2884	170,00	6800	0,42
21	B1+M1+M4	6,50	2600	112,50	4500	0,58
25	B1+M1	10,40	4160	149,65	5986	0,69
26	B1+M1	9,94	3976	321,20	12848	0,31
27	M1	6,83	2732	153,50	6140	0,44
28	M1	3,78	1512	88,80	3552	0,43
30	B1+B2	6,39	2556	142,30	5692	0,45
Average per day:		-	5492	-	2486	0,50
SEPT. 24	B1	3,20	1280	33,15	1326	0,97
25	B1+M4	4,08	1632	84,35	3374	0,48
26	M1	2,09	836	61,75	2470	0,34
27	M1	2,73	1092	67,20	2688	0,41
28	M1+M3	4,51	1804	86,60	3464	0,52
29	B1+M3	4,64	1856	87,30	3492	0,53
Average per day:		-	1417	-	2802	0,54

Appendix 3.21

Energy consumption and water discharge data of
irrigation units
1979

MEZŐHÉK II.

Date	Pumps operated	Electric energy		Water discharge		Specific energy kWh/m ³
		Meter	kWh	Meter	m ³	
JUNE	1 B1+B2+M2+M3	19,40	7760	511,30	20452	0,38
	2 B1+B2+M2+M3	19,26	7704	553,00	21320	0,35
	3 M2+M3	13,10	5240	386,70	15468	0,34
	4 B1+B2 M2	6,40	2560	293,60	11744	0,22
	5 B1+B2+M3+M3	17,50	7000	486,50	19460	0,36
	6 B1+B2+M2+M3	16,90	6760	483,10	19424	0,35
	7 M2+M3	19,60	7840	569,20	22796	0,34
	8 B1+B2+M2+M3	19,80	7920	601,80	24072	0,33
	9 B1+B2+M2+M3	16,10	6440	463,00	18520	0,35
	10 B1+B2+M2+M3	22,50	9000	652,70	26108	0,34
	11 B1+B2+M2+M3	18,10	7240	470,60	18824	0,38
	12 B1+B2+M1+M2+M3	20,90	8360	616,20	24648	0,34
	13 B1+B2+M1+M2+M3	18,20	7280	520,40	20816	0,35
	14 B2+M1+M3	14,70	5880	419,90	16796	0,35
	15 B1+B2+M1	7,50	3000	218,20	8728	0,34
	29 M1	3,80	1520	118,10	4724	0,32
	30 B1+B2+M1	6,50	2600	265,90	10636	0,24
JULY	2 B1+B2+M1	7,30	2920	421,20	16848	0,17
	3 B1+B2+M4	10,60	4240	958,10	38324	0,11
	4 B1+B2	7,10	2840	234,30	9372	0,30
	5 B1+B2	4,50	1800	193,00	7720	0,23
	8 B1+B2	2,00	800	135,80	5432	0,15
	10 B1+B2	7,50	3000	124,10	4964	0,60
	11 B1+B2+M1	8,30	3320	135,80	5432	0,61
	12 B1+B2+M1	8,80	3520	173,20	6928	0,51
	13 B1+B2+M1	9,30	3720	157,80	6312	0,59
	16 B2+M1	2,50	1000	47,70	1908	0,52
	17 B1+B2	5,80	2320	263,60	10544	0,22
	18 B1+B2+M1	14,80	5920	400,20	16008	0,37
	19 B1+B2+M1	12,00	4800	395,00	15800	0,30
	20 B1+B2+M1	13,20	5280	181,40	7256	0,73
	21 B1+B2+M1	5,70	2280	59,60	2384	0,96
	23 B1+B2+M3	2,00	800	79,80	3192	0,25
	24 B1+B2+M3	5,70	2280	147,80	5912	0,39
	25 B2+M3	6,40	2560	165,70	6628	0,39
	26 B1+B2+M3	6,90	2760	151,60	6064	0,46
	30 B1+B2+M3	3,20	1280	43,60	1744	0,73
	31 B1+B2+M3	9,00	3600	181,70	7388	0,49
Average per day:		-	2907	-	8865	0,43

Appendix 3.22Energy consumption and water discharge
data of sprinkler irrigation units

1979.

MEZŐHÉK II.

Date	Pumps operated	Electric energy		Water dis- charge		Specific energy kWh/m ³
		Meter	kWh	Meter	m ³	
AUG. 9	B1+B2+M3	9,6	3840	177,30	7092	0,54
10	B1+M1	9,3	3720	168,00	6720	0,55
11	B1+B2+M1	4,10	1640	112,20	4480	0,37
13	B1+B2+M1	7,50	3000	117,90	4716	0,64
14	B1+B2+M1	9,20	3680	131,60	5264	0,70
15	B1+B2+M1	9,50	3800	104,50	4180	0,91
16	B1+B2+M1	10,30	4120	209,50	8380	0,49
17	B1+B2+M1	8,80	3520	92,00	3680	0,96
Average per day: -		-	3415	-	5565	0,65
SEPT. 18	B1+B2	2,50	1000	38,10	1524	0,66
21	B1+B2	6,40	2560	229,10	9164	0,28
22	B1+B2	7,00	2800	169,20	6768	0,41
24	B1+B2	6,70	2680	386,70	15468	0,17
25	B1+B2	6,90	2760	227,30	9092	0,30
26	B1+B2	6,60	2640	208,90	8356	0,32
27	B1+B2	6,90	2760	224,30	8972	0,31
28	B1+B2	6,90	2760	245,40	9816	0,28
29	B1+B2	6,80	2720	261,00	10440	0,26
Average per day: -		-	2520	-	8844	0,23

Appendix 3.23

Energy consumption and water discharge
data of sprinkler irrigation units

1979.

TISZAFÖLDEVÁR I.

Date	Pumps operated	Electric energy		Water dis- charge		Specific energy kWh/m ³
		Meter	kWh	Meter	m ³	
JUNE	1	B1+B2+M1+M4	10,06	4020	585,50 23420	0,17
	2	B1+B2+M1+M4	10,36	4144	624,60 24984	0,17
	3	B1+B2+M4	6,92	2768	411,40 16456	0,17
	5	B1+B2+M4	11,70	4680	825,60 33024	0,14
	6	M4	12,60	5040	892,40 35696	0,14
	7	B1+B2+M4	7,01	2804	448,00 17920	0,16
	8	B1+B2	5,25	2100	216,10 8644	0,24
	14	B2+M1	7,67	3068	295,80 11832	0,26
	16	B1+B2+M4	8,39	3356	253,40 10136	0,33
Average per day: -		-	3553	-	20234	0,20

TISZAFÖLDEVÁR II.

JUNE	6	B1+B2+M2	1,90	760	60,30 2412	0,32
	7	B1+B2+M2	5,40	2160	559,50 22380	0,10
	8	B1+B2+M2	5,70	2280	562,30 22492	0,10
	9	B1+B2+M2	5,00	2000	261,10 10444	0,19
	10	B1+B2+M2	4,40	1760	492,90 19716	0,09
	11	B1+B2+M2	3,20	1280	234,30 9372	0,14
	12	B1+B2+M2	5,00	2000	553,30 22132	0,09
	13	B1+B2+M2	8,20	3280	111,70 4468	0,73
Average per day: -		-	1940	-	14177	0,22

Appendix 3.24

Energy consumption and water discharge
data of sprinkler irrigation units
1979.

KUNGYALU

Date		Pumps Operated	Electric energy		Water discharge		Specific energy kWh/m ³
			Meter	kWh	Meter	m ³	
JUNE	6	B2+M1+M3	20,40	8160	782,00	31280	0,26
	7	B2+M1+M2+M3	21,80	8720	854,30	34172	0,26
	8	B2+M1+M3	20,20	8080	768,70	30748	0,26
	9	B2+M1+M3	22,20	8880	824,10	32964	0,27
	10	B2+M1+M3	18,40	7360	682,70	27308	0,27
	11	B2+M1+M3	13,50	5400	501,70	20068	0,27
	12	B2+M1+M3	23,50	9400	908,60	36344	0,26
	13	B2+M1+M3	17,00	5200	614,30	24572	0,28
	14	B2+M1+M3	24,30	9720	921,50	36860	0,26
	15	B2+M3	4,50	1800	177,60	7104	0,25
	16	B2+M1+M3	22,10	8840	570,70	22828	0,39
	18	B2+M3	18,80	7520	720,20	28808	0,26
	19	B2+M3	14,70	5880	536,20	21448	0,27
	20	B2+M1+M3	17,10	6840	640,40	25616	0,27
	21	B2+M1	10,20	4080	456,40	18256	0,22
	22	B2+M1	10,40	4160	453,10	18124	0,23
	25	B2+M1	10,30	4120	504,30	20172	0,20
	26	B2+M1+M2	12,80	5120	529,30	21172	0,24
	27	B2+M1+M2	14,40	5760	574,90	22996	0,25
	28	B2+M1+M2+M3	15,80	6320	607,40	24296	0,26
	29	B2+M1+M2+M3	14,00	5600	531,00	21240	0,26
	30	M2+M3	14,10	5640	616,60	24664	0,23
Average per day:				6482		25047	0,25
JULY	12	B2+M1+M2+M3	8,40	3360	392,00	15680	0,21
	13	M1+M3	14,70	5880	533,30	21332	0,28
	14	M1+M3	13,80	5520	494,40	19776	0,28
	16	M1+M3	11,20	4480	465,60	18624	0,24
	17	M4+M3	10,00	4000	294,90	11796	0,34
	18	M4+M2	9,00	3600	281,30	11252	0,32
	19	B2+M1+M2	14,70	5880	339,00	13560	0,43
	20	B2+M2	5,50	2200	365,70	14628	0,15
	24	B2+M2+M3	17,70	7080	358,10	14324	0,49
	25	M3	4,80	1920	358,90	14356	0,13
	26	B2+M3	5,50	2200	204,90	8196	0,27
	27	B2+M3	7,70	3080	261,60	10464	0,29
	28	B2+M3	4,60	1840	135,50	5420	0,34
	30	B2+M2	4,70	1880	155,00	6200	0,30
Average per day:			-	3780	-	13258	0,29

Appendix 3.25

Energy consumption and water discharge
data of sprinkler irrigation units
1980.

MEZŐHÉK I.

Date		Pumps operated	Electric energy		Water dis- charge		Specific energy ₃ kWh/m ³
			Meter	kWh	Meter	m ³	
JULY	15	B1+M3	9,10	3640	428,80	17152	0,21
	16	B1+M3	7,95	3180	293,50	11740	0,27
	17	B1+B2+M3	7,46	2984	305,40	12216	0,24
	18	M3	8,13	3252	363,90	14556	0,22
	19	B1+M3	10,13	4052	323,60	12944	0,31
	21	B1+B2+M3	7,96	3184	311,50	12460	0,26
	22	M3	16,14	6456	309,80	12392	0,52
	23	M3	4,94	1976	313,70	12548	0,16
	24	M4	3,36	1344	304,20	12168	0,11
	25	B1+B2+M3	7,68	3072	257,30	10292	0,30
	28	B1+B2+M3	8,35	3340	280,50	11220	0,30
	29	B1+B2+M3	6,63	2652	257,30	10292	0,26
Average per day:			-	3261	-	12498	0,26
AUG.	5	B1+B2+M3	7,79	3116	240,10	9604	0,32
	6	B1+B2+M3	7,50	3000	233,15	9326	0,32
	7	B1+B2+M3	7,55	3020	238,40	9536	0,32
	8	B1+B2+M3	5,75	2400	158,90	6356	0,37
	11	B1+B2+M3	7,05	3176	140,30	5612	0,57
	12	B1+B2+M3	7,25	2900	210,10	8404	0,35
	13	B1+B2+M3	7,27	2908	228,50	9140	0,32
	14	B1+M3	15,10	6040	491,80	19672	0,31
	15	B1+M3	7,39	2956	236,90	9476	0,31
	16	B1+M3	3,55	1420	99,80	3992	0,36
	18	M3	7,50	3000	232,80	9312	0,32
	19	B1+M3	7,65	3060	241,70	9668	0,32
	21	M3	5,97	2388	229,69	9188	0,26
	22	B1+M3	9,38	3752	240,01	9600	0,39
	25	B1+M3	6,12	2448	181,05	7242	0,34
	26	B1+B2	6,21	2484	155,55	6222	0,40
	27	B1+B2	3,10	2876	71,00	3120	0,92
	29	B1+B2	7,19	1240	78,00	2860	0,43
	30	B1+B2	1,65	660	32,85	1314	0,50
Average per day:			-	2781	-	7876	0,39

Appendix 3.26

Energy consumption and water discharge
data of sprinkler irrigation units

1980.

MEZŐHÉK II.

Date		Pumps operated	Electric energy		Water discharge		Specific energy kWh/m ³
			Meter	kWh	Meter	m ³	
JULY	10	M1	7,9	3160	657,3	26292	0,12
	11	B1+B2+M1	6,9	2760	462,0	18480	0,15
	14	B1+B2+M3	7,0	2800	492,0	19680	0,14
	15	B1+B2+M3	3,9	1560	187,4	7496	0,21
	16	B1+B2+M3	6,8	2720	342,4	13696	0,20
	17	B1+B2+M3	8,3	3320	532,9	21316	0,16
	18	B1+B2	7,7	3080	511,6	20464	0,15
	19	B1+B2+M3	4,8	1920	287,0	11480	0,17
	21	B1+B2+M3	7,0	2800	449,0	17960	0,16
	22	B1+B2+M3	6,3	2520	409,9	16396	0,15
	23	B1+B2	4,1	1640	202,9	8116	0,20
	24	B1+B2+M3	4,8	1920	255,8	10232	0,19
	25	M3	6,1	2440	446,4	17856	0,14
	26	B1+B2	4,0	1600	230,0	9200	0,17
	28	M3	6,5	2600	436,2	17448	0,15
	29	B1+B2+M2	5,1	2040	240,0	9600	0,21
	30	B1+B2	2,5	1000	113,3	4532	0,22
	31	M3	6,1	2440	374,8	14992	0,16
Average per day:			-	2351	-	14735	0,17
AUG.	4	M3	5,9	2360	338,1	13524	0,17
	5	B1+B2+M3	9,7	3880	615,7	24628	0,16
	6	B1+B2	3,9	1560	256,8	10272	0,15
	7	B1+B2+M3	5,7	2280	436,2	17448	0,13
	8	B1+B2+M3	5,3	2120	339,4	13576	0,16
	11	B1+B2+M3	7,6	3040	539,5	21580	0,14
	12	B1+B2+M3	9,2	3680	632,3	25292	0,15
	13	B1+B2+M3	6,5	2600	646,4	25856	0,10
	14	B1+M3	7,5	3000	540,1	21604	0,14
	15	B1+B2+M3	7,3	2920	531,3	21252	0,14
	16	B1+B2+M3	5,1	2040	406,7	16268	0,13
	17	B1+B2	5,2	2080	427,6	17104	0,12
	18	B1+B2+M3	5,4	2160	430,8	17232	0,13
	19	B1+B2+M3	8,2	3280	610,0	24400	0,13
	21	B1+B2+M3	6,1	2440	570,8	22832	0,11
	22	B1+B2+M3	6,5	2600	589,2	23568	0,11
	23	B1+B2	3,3	1320	354,7	14188	0,09
	25	B1+B2+M3	4,7	1880	399,3	15972	0,12
	26	B1+B2+M3	5,0	2000	469,2	18768	0,11
	27	B1+B2	4,3	1720	360,9	14436	0,12
	29	B1+B2+M3	4,7	1880	431,0	17240	0,11
	30	B1+B2	1,8	720	114,3	4572	0,16
Average per day:			-	2344	-	18255	0,13

Irrigation pump operation data

Mezőhék No. I

7./day/. August. 1980

Operation hour	Operated pumps	Water discharge l/s		Irrigation mach.	Water consumption		Energy consumption		Pumping pressure m	Electric power kW
		Pumps nominal	Meter state		Meter state	m'	Meter state	kWh		
5	B ₁ +B ₂	110	—	196	79177,9	—	3687,75	—	—	—
6	M ₃	200	215	196	79195,8	716	3688,32	228	74,0	235
7	M ₃	200	200	196	79214,5	748	3688,90	232	74,0	231
8	B ₁ +B ₂	110	66	62	79224,9	416	3689,29	156	87,0	122
9	M ₃	200	176	196	79241,0	644	3689,82	212	78,0	214
10	M ₃	200	210	196	79259,6	744	3690,40	232	72,0	224
11	M ₃	200	210	196	79278,3	748	3690,96	224	72,0	224
12	M ₃	200	198	196	79295,9	704	3691,51	220	75,0	219
13	M ₃	200	176	196	79313,2	692	3692,08	228	78,0	177
14	M ₃	200	210	196	79330,9	708	3692,63	220	72,0	224
15	B ₁ +B ₂	110	110	98	79344,1	528	3693,09	184	73,5	147
16	M ₃	200	220	196	79359,4	612	3693,57	192	69,15	228
17	M ₃	200	215	196	79378,5	764	3694,15	232	72,0	228
18	M ₃	200	218	196	79397,5	760	3694,74	236	72,0	228
19	M ₃	200	218	196	79416,3	752	3695,30	224	72,0	224

Irrigation pump operation data

..8./day/.....1980

Mezőhek No. I

Operation hour	Operated pumps	Water discharge l/s		Irrigation mach.	Water consumption		Energy consumption		Pumping pressure m	Electric power kW
		Pumps nominal	Meter state		Meter state	m'	Meter state	kWh		
5	B ₁ +B ₂	110	—	196	79416,4	—	3695,48	—	58,5	—
6	M ₃	200	215	196	79433,8	696	3696,03	220	72,0	227
7	M ₃	200	176	106	79452,4	744	3696,60	228	79,5	224
8	B ₁ +B ₂	110	88	90	79464,7	492	3697,09	196	81,0	133
9	M ₃	200	132	154	79475,4	428	3697,53	176	87,0	197
10	B ₁ +B ₂	110	110	143	79488,4	520	3697,99	184	67,5	149
11	B ₁ +B ₂	110	100	143	79497,7	372	3698,34	140	75,0	144
12	B ₁ +B ₂	110	110	143	79506,6	356	3698,75	164	75,0	123
13 ⁺	B ₁ +B ₂	110	—	106	—	—	—	—	—	—
14	B ₁ +B ₂	110	77	82	79524,7	726	3699,51	304	85,5	125
15	B ₁ +B ₂	110	110	86	79531,8	284	3699,84	132	67,5	123
16	B ₁ +B ₂	110	110	86	79541,9	402	3700,21	148	67,5	150
17 ⁺⁺	—	—	—	—	—	—	—	—	—	—
18	M ₃	200	175	152	79567,0	764	3700,96	300	79,0	217
19	M ₃	200	165	152	79575,3	572	3701,48	208	78,0	218

+ : Readings not noted

++ : Operation break

Irrigation pump operation data

Mezőhek No. I

12./day/AUGUST...1980

Operation hour	Operated pumps	Water discharge l/s		Irrigation mach.		Water consumption		Energy consumption		Pumping pressure m	Electric power kW
		Pumps nominal	Meter state			Meter state	m'	Meter state	kWh		
5	B ₁ +B ₂	110	—	152	—	79715,8	—	3709,58	—	—	—
6	M ₃	200	150	152	540	79729,3	540	3710,10	208	84,0	202
7	B ₁ +B ₂	110	110	108	564	79743,4	564	3710,63	212	75,0	146
8	B ₁ +B ₂	110	105	108	368	79752,6	368	3711,00	148	72,0	141
9	M ₃	200	176	108	416	79763,0	416	3711,39	156	79,5	211
10	M ₃	200	154	108	556	79776,9	556	3711,89	200	81,0	205
11	M ₃	200	187	108	612	79792,2	612	3712,44	220	75,0	221
12	M ₃	200	187	108	660	79808,7	660	3713,00	224	75,0	221
13	M ₃	200	187	108	660	79825,2	660	3713,56	224	75,0	220
14	M ₃	200	176	108	460	79836,7	460	3713,99	172	80,0	234
15	M ₃	200	209	128	692	79854,0	692	3714,58	236	72,0	224
16	M ₃	200	209	128	704	79871,6	704	3715,12	216	72,0	224
17	M ₃	200	209	128	700	79889,1	700	3715,69	228	72,0	223
18	M ₃	200	209	128	732	79907,4	732	3716,25	224	72,0	224
19	M ₃	200	209	128	740	79925,9	740	3716,83	232	72,0	223

Appendix 3.30

Operational details of sprinkler laterals

MEZŐHÉK I.

Date	Field No.	Crops	Hydrant		Irrigation		Lateral	No.	Total l/s	Daily operation hours
			No.	type	No.	Sprinkler				
7.VIII.80.	H1	Sugarbeet	1.9/5	VOLZS.	2	VOLZS.		46	46	12,5
	H1	Sugarbeet	1.7/2	VOLZS.	2	VOLZS.		44	44	12,5
	H7	Sugarbeet	1.2/6	OBA	1	TISZA-II.		10	20	12,75
	H5	Alfalfa	3.5/3	VOLZS.	2	TISZA-II.		22	44	12,5
	H9	Sugarbeet	3.1/6	VOLZS.	2	TISZA-II.		21	42	12,5
8.VIII.80.	H1	Sugarbeet	1.9/5	VOLZS.	2	VOLZS.		46	46	5,25
	H1	Sugarbeet	1.7/2	VOLZS.	2	VOLZS.		44	44	11,5
	H7	Sugarbeet	1.2/5	OBA	1	TISZA-II.		10	20	11,5
	H5	Alfalfa	3.5/2	VOLZS.	2	TISZA-II.		22	44	6,5
	H9	Sugarbeet	3.1/6	VOLZS.	2	TISZA-II.		21	42	13,5
12.VIII.80.	H1	Sugarbeet	1.9/6	VOLZS.	2	VOLZS.		46	46	11,5
	H1	Sugarbeet	1.7/1	VOLZS.	2	VOLZS.		44	44	0,5
	H7	Sugarbeet	1.2/4	OBA	1	TISZA-II.		10	20	4,75
	H11	Sugarbeet	2.1/3	OBA	1	TISZA-II.		10	20	13,0
	H9	Sugarbeet	3.1/5	VOLZS.	2	TISZA-II.		21	42	12,5

```

1  C PROGRAM FOR EVALUATION OF DISCHARGE-PRESSURE DIAGRAM
2      MASTER SK02
3      DIMENSION XE(225),YE(225),X(14),Y(14),U(14),V(14)
4      DATA K/4H****/
5      READ(1,600) KS,(U(I),I=1,14)
6      600 FORMAT(10/(F0.0))
7
8  PUMPING 101 IN LINE      6 ITEM      10
9      CALL RALT(3)
10     CALL RHOL(2,KK,01)
11     READ(1,100) XE
12     100 FORMAT(16F5.0)
13     CALL RALT(3)
14     CALL RHOL(2,KOD,1)
15     READ(1,100) YE
16     M=225
17     JK=1
18     JV=17
19     DO 40 I=1,14
20         X(I)=0.
21         40 Y(I)=0.
22         DO 50 J=1,14
23             DO 60 J=JK,JV
24                 X(I)=X(I)+XE(J)
25                 60 Y(I)=Y(I)+YE(J)
26                 XA=FLOAT(JV-JK+1)
27                 X(I)=0.15*0.0980665*X(I)/XA
28                 Y(I)=13.75*Y(I)/XA
29                 JK=JV+1
30                 50 JV=JK+15
31                 IE=4
32                 WRITE(5,200) KS
33                 200 FORMAT(1H1,10X,41H EVALUATION OF DISCHARGE-PRESSURE DIAGRAM, //16X,
34                     7
35                     *25H PUMPING UNIT : MEZOHEK I, /16X, 7H DATE: ,13,15H. AUGUST, 1980.,
36                     7
37                     *////10X,4HTIME,6X,7HAVERAGE,8X,7HAVERAGE,3X,15HSPECIFIC ENERGY,
38                     *3X,12HPUMPING UNIT,/,20X,9HDISCHARGE,5X,8HPRESSURE,5X,
39                     *11HCONSUMPTION,5X,10HEFFICIENCY,/,10X,5HHOURS,7X,7HLIT/SEC,9X,
40                     *3HMPA,7X,7HKWH/CUM,8X,7HPERCENT,/)
41                     DO 70 I=1,14
42                         IE=IE+1
43                         IV=IE+1
44                         IF(U(I).EQ.0.) GOTO 80
45                         V(I)=27.2*X(I)/U(I)
46                         WRITE(5,400) IE,IV,Y(I),X(I),U(I),V(I)
47                         400 FORMAT(8X,I3,1H-,I3,F13.2,F13.2,F13.3,F15.2)
48                         GOTO 70
49                         80 WRITE(5,300) IE,IV,K,K,K,K
50                         300 FORMAT(8X,I3,1H-,I3,9X,A4,9X,A4, 9X,A4,11X,A4)
51                         70 CONTINUE
52                         STOP
53                         END

```

OCEDURE SK02 IN TRACE 0
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PROGRAM SK02

EVALUATION OF DISCHARGE-PRESSURE DIAGRAM

PUMPING UNIT : MEZOHEK I
DATE: 7. AUGUST, 1980.

TIME HOURS	AVERAGE DISCHARGE LIT/SEC	AVERAGE PRESSURE MPA	SPECIFIC ENERGY CONSUMPTION KWH/CUM	PUMPING UNIT EFFICIENCY PERCENT
5- 6	195.74	0.64	0.318	54.70
6- 7	203.67	0.73	0.310	63.73
7- 8	117.73	0.81	0.375	58.95
8- 9	185.62	0.77	0.329	63.47
9- 10	207.11	0.72	0.312	63.08
10- 11	205.39	0.72	0.299	65.74
11- 12	193.36	0.76	0.313	65.75
12- 13	193.36	0.77	0.329	63.92
13- 14	197.66	0.74	0.311	64.97
14- 15	141.80	0.76	0.348	59.71
15- 16	194.22	0.70	0.314	61.00
16- 17	220.00	0.71	0.304	63.18
17- 18	220.00	0.71	0.311	61.83
18- 19	193.36	0.63	0.298	57.57

EVALUATION OF DISCHARGE-PRESSURE DIAGRAM

PUMPING UNIT : MEZOHEK I
DATE: 8. AUGUST, 1980.

Appendix 3.33

TIME HOURS	AVERAGE DISCHARGE LIT/SEC	AVERAGE PRESSURE MPA	SPECIFIC ENERGY CONSUMPTION KWH/CUM	PUMPING UNIT EFFICIENCY PERCENT
5- 6	197.35	0.68	0.316	58.54
6- 7	195.08	0.73	0.306	65.30
7- 8	101.41	0.83	0.398	56.80
8- 9	108.28	0.86	0.411	57.07
9- 10	122.03	0.74	0.354	56.58
10- 11	85.94	0.73	0.376	53.07
11- 12	82.50	0.76	0.461	45.13
12- 13	***	***	***	***
13- 14	84.22	0.88	0.419	57.35
14- 15	67.89	0.84	0.465	49.26
15- 16	96.25	0.69	0.368	51.17
16- 17	***	***	***	***
17- 18	134.06	0.69	0.393	47.91
18- 19	122.03	0.77	0.364	57.50

EVALUATION OF DISCHARGE-PRESSURE DIAGRAM

PUMPING UNIT : MEZOHEK I
DATE: 12. AUGUST, 1980.

Appendix 3.34

TIME HOURS	AVERAGE DISCHARGE LIT/SEC	AVERAGE PRESSURE MPA	SPECIFIC ENERGY CONSUMPTION KWH/CUM	PUMPING UNIT EFFICIENCY PERCENT
5- 6	139.12	0.72	0.385	51.17
6- 7	145.23	0.83	0.376	59.92
7- 8	97.11	0.74	0.402	49.83
8- 9	119.45	0.75	0.375	54.62
9- 10	144.37	0.78	0.360	58.70
10- 11	169.30	0.77	0.359	58.44
11- 12	178.75	0.75	0.339	60.19
12- 13	173.59	0.76	0.339	61.15
13- 14	126.33	0.76	0.374	55.63
14- 15	190.78	0.75	0.341	60.06
15- 16	192.50	0.74	0.307	65.49
16- 17	186.48	0.75	0.326	62.59
17- 18	192.50	0.72	0.306	64.07
18- 19	180.47	0.72	0.314	62.28

Date: Sept. 23, 1980 Hydrant No.: 3316
Lateral type: VOLZSANKA Length: 277.2 + 252.0 = 529.2 m
Sprinkler types: Ts2A II No.: 21 / Dia. 10.2 mm /

[illegible]

Irrigation machine operation data

App.

Date: Sept. 24. 1980 Hydrant No.: 33/7 Mezőhék No. -
 Lateral type: Volzsanka Length: 277,2+252,0 = 529,2 m
 Sprinkler types: Tiszai II No.: 21 /Dia. 10,2 mm/, 3 /Dia. 8,6 mm/

Time	Hydrant pressure /m/	Hydrant operation readings					Pressure at sprinkler /m/				Pump operation readings			
		p/mm hg/	Q/l/s/	V /m ³ /	No. 1 (1)	No. 2 (2)	No. 3 (3)	No. 4 (4)	No.	m'	m	kWh		
8-45	33,5	311	37,67	33,90	21,0	25,2	24,2	22,0	B ₁ +B ₂	85,2	80,0	28		
9-00	33,3	300	36,97	33,27	20,0	25,2	24,2	22,0	B ₁ +B ₂	72,0	81,0	32		
9-15	27,5	247	33,58	30,22	18,0	21,0	20,0	19,8	B ₁ +B ₂	68,0	82,0	32		
9-30	22,5	200	30,18	27,16	14,2	16,0	14,8	15,8	B ₁ +B ₂	71,6	84,0	36		
9-45	17,5	162	27,17	24,35	10,1	13,0	11,5	10,0	B ₁ +B ₂	72,4	81,0	28		
10-00	34,5	307	37,42	33,68	24,0	26,1	26,0	22,9	B ₁ +B ₂	82,8	81,0	52		
10-15	32,5	287	36,18	32,56	22,0	25,0	24,0	23,2	B ₁ +B ₂	64,8	81,0	16		
10-30	27,5	245	33,41	30,07	18,2	21,5	20,0	19,8	B ₁ +B ₂	72,0	82,7	24		
10-45	22,5	192	29,61	26,65	15,0	16,5	15,8	16,0	B ₁ +B ₂	71,6	84,0	32		
11-00	17,5	152	26,34	23,71	11,0	13,5	11,8	12,0	B ₁ +B ₂	64,4	83,7	52		
11-15	35,0	306	37,34	33,61	24,0	27,5	26,1	23,2	B ₁ +B ₂	68,8	81,0	16		
11-30	32,5	282	35,85	32,27	20,0	25,1	24,1	22,0	B ₁ +B ₂	80,4	81,5	28		
11-45	27,5	236	32,79	29,51	15,0	21,2	20,0	18,8	B ₁ +B ₂	69,6	84,0	32		
12-00	22,5	185	29,82	26,12	13,0	16,1	15,2	15,5	B ₁ +B ₂	66,4	84,0	32		
12-15	17,5	152	26,34	23,71	11,0	13,0	11,0	9,6	B ₁ +B ₂	68,8	84,0	28		

1. Calculation of water discharge through orificeplate^{1/}

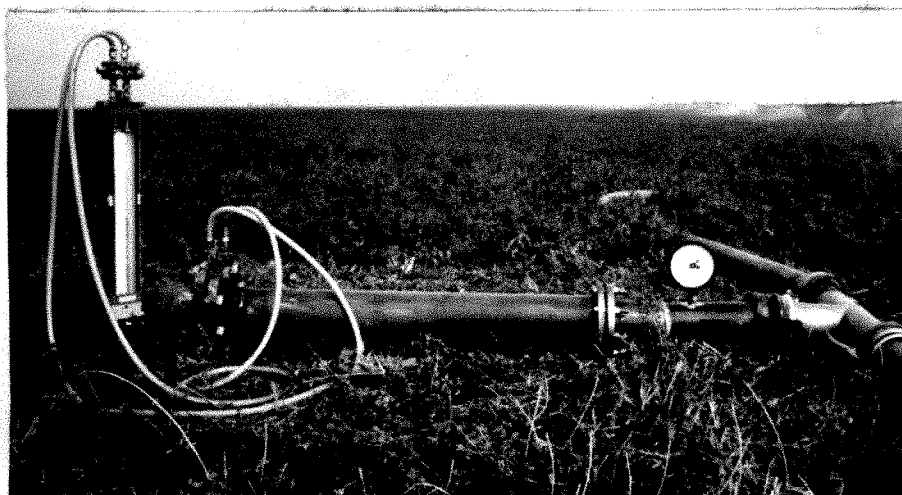


Fig. 3.37.1

Following procedure for calculation of water discharge through orifice plate is used only when:

$$50 \text{ mm} \leq D \leq 760 \text{ mm}$$

$$0,1 \leq \beta \leq 0,75$$

Since our case satisfy these conditions we have adopted it.

$$q_v = \alpha \cdot \epsilon \cdot \frac{d^2 \pi}{4} \sqrt{\frac{2 \Delta p}{\rho}} \quad [1]$$

Where: q - water discharge /m³/s/
 α - coefficient of discharge /dimensionless/
 ϵ - expansion number /dimensionless/ /for water = 1/
 Δp - measured pressure difference across the orifice plate /N/m²/
 ρ - density of water /kg/m³/ /for water = 1000/

The coefficient of discharge / α / is calculated as below:

$$\alpha = \left[1 + \frac{\beta \cdot A}{Re \cdot D} \right] \quad [2]$$

Where: β - diameter ratio /dimensionless/
 /In our case = 0,6/

1/ As per the Hungarian Standard., Fluid flow measurements;
 Measurements by means of orifice plates, MSZ 1709/3, No.67.

$$\alpha = \alpha_e \left[\frac{10^6 \cdot d}{10^6 \cdot d + 384 A} \right]$$

Appendix 3.37

α_e and A are calculated as below:

$$\begin{aligned} \alpha_e = & 0,5993 + \frac{0,1778}{D} + \left[0,364 + \frac{0,3830}{\sqrt{D}} \right] \beta^4 + 0,4 \left[1,6 - \frac{25,40}{D} \right]^5 \\ & \left[\left(0,07 + \frac{12,70}{D} \beta \right)^{5/2} - \left[0,009 + \frac{0,8636}{D} \right] \left[0,5 - \beta \right]^{3/2} \right. \\ & \left. + \left[\frac{41935}{D^2} + 3 \right] \left[\beta - 0,7 \right]^{5/2} \right] \end{aligned} \quad [4]$$

$$A = 0,03937d \left[830 - 500\beta + 9000\beta^2 - 4200\beta^3 + \frac{2671}{D} \right] [5]$$

In the above equations [4] and [5] if some value becomes imaginary, then it is equated to zero.

$$ReD = \frac{\bar{v} D}{\nu} \quad [6]$$

Where:

ReD = Reynolds number for flow through D

$\bar{v}$ - average velocity /m/s/

ν - kinetic viscosity /m²/s/

/for water = 1,169 · 10⁻⁶/

The average velocity $\bar{v}$ was calculated as follows:

$$\bar{v} = \frac{\frac{4q_1}{D^2} + \frac{4q_2}{D^2}}{2} \quad /m/s/ \quad [7]$$

Where: q_1 and q_2 are minimum and maximum discharges to be measured, and are approximated from calibration curve for the given orificeplate Fig. 3.37.1.

In our case following values for q_1 and q_2 were approximated based upon the observed Δp for the given hydrant.

Hydrant	Date	q_1 /l/s/	q_2 /l/s/
33/6	23.9.80	24,28	32,56
33/7	24.9.80	26,15	37,85

Appendix 3.37

Considering the approximated discharge values, the value of α is calculated using equations [2], [3], [4], [5], [6] and [7].

The results are presented in tabular form as follows:

Symbol	Equation No.	Hydrant No.	
		33/6	33/7
v	[7]	1,60 m/s	1,81 m/s
ReD	[6]	20544,5	232249,8
A	[5]	1349,43	
α_e	[4]	0,6517	
α^i	[3]	0,6480	
α	[2]	0,65055	0,65026

By putting the respective values of α and average values of Δp in the equation [1] the respective values of water discharges were calculated.

2. Calculation of pressure at hydrant

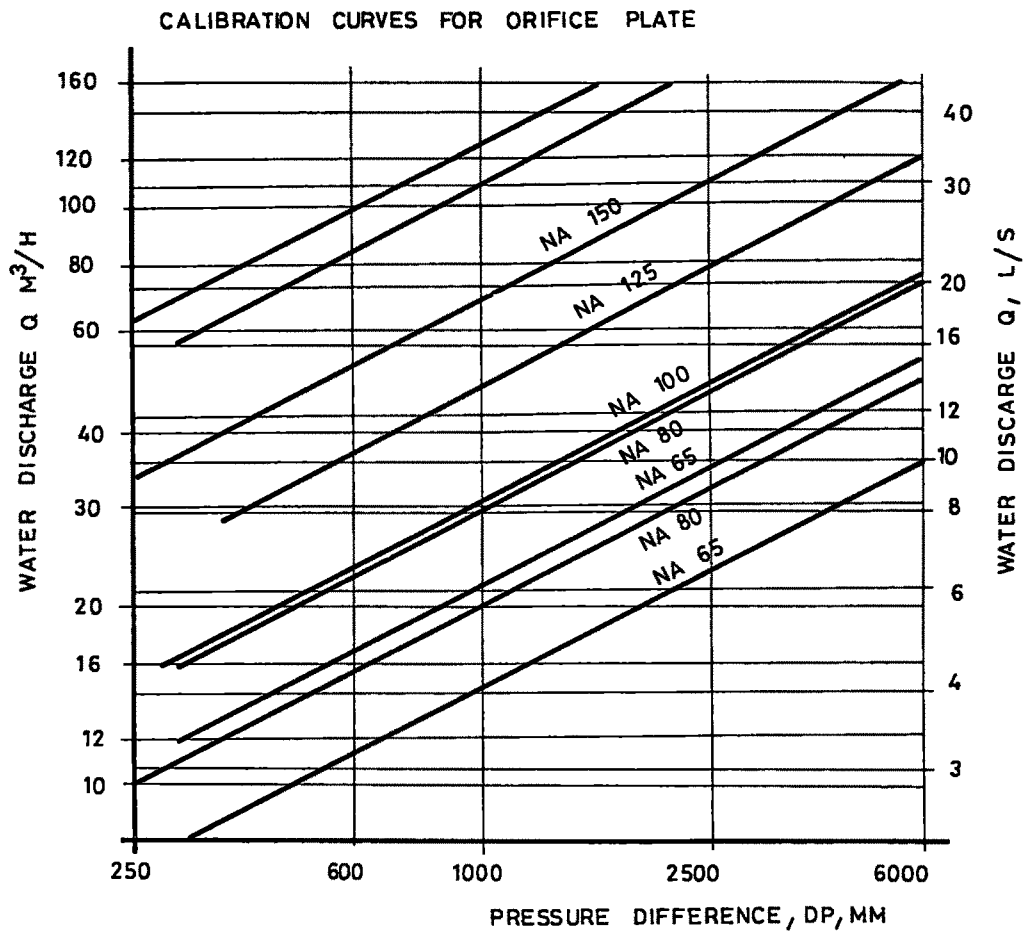
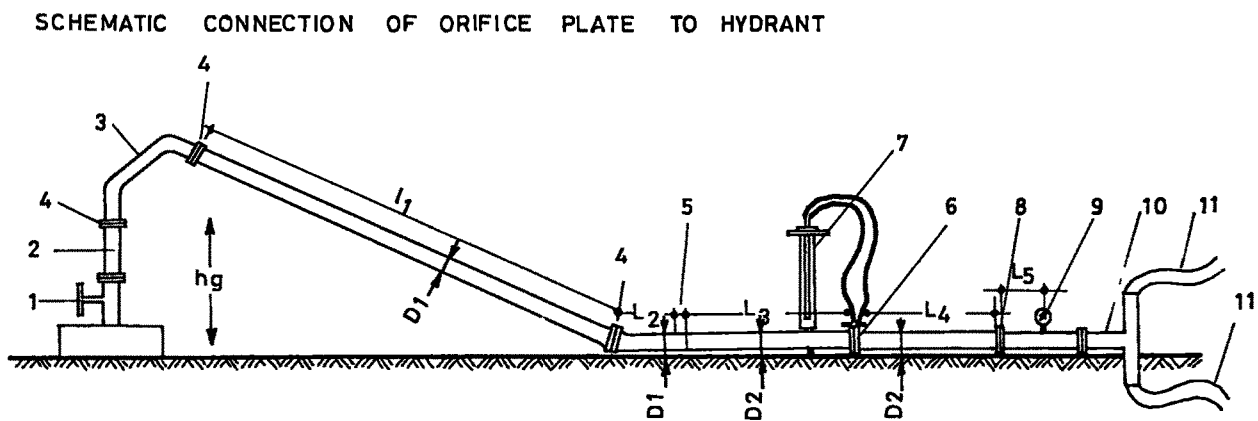
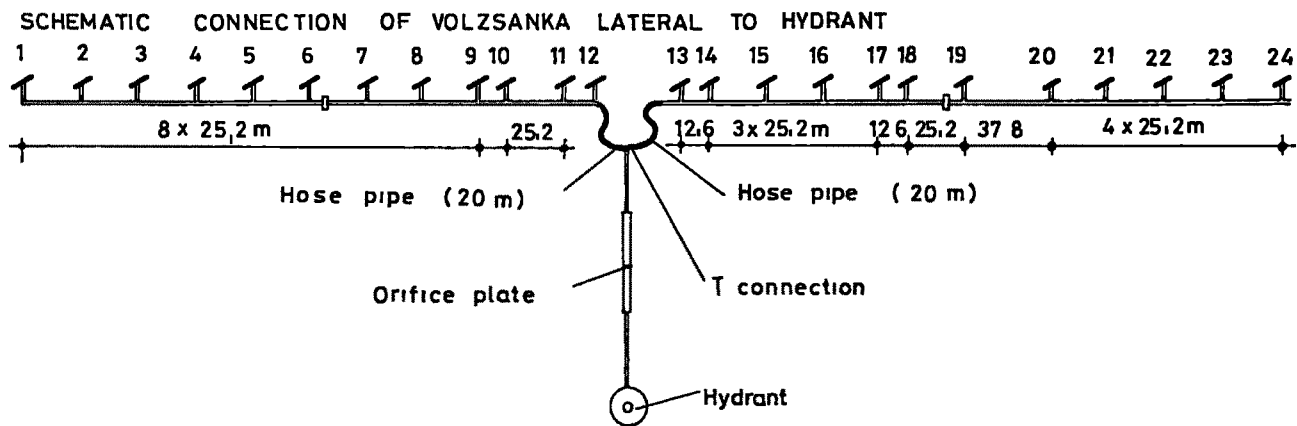


Fig. 3.37.2



Appendix 3.37

1 - Hydrant valve; 2 - Hydrant; 3 - Hydrant bend;
 4 - Couplers; 5 - Diffusers; 6 - Orifice-plate;
 7 - Manometer; 8 - Converger; 9 - Pressure gauge;
 10 - T-bend; 11 - Hoses for lateral; $L_1 = 6$ m; $L_2 = 0,34$ m;
 $L_3 = 2,1$ m; $L_4 = 1,2$ m; $L_5 = 0,11$ m; $D_1 = 0,13$ m;
 $D_2 = 0,15$ m; $d = 0,090$ m; $h_g = 1$ m.

The total hydrant pressure:

$$H_h = h_b + h_{p1} + h_c + h_{p2} + h_{dif} + h_{p3} + h_o + h_{p4} + h_{con} + h_{p5} + h_{pg} - h_g \quad [1]$$

where: h_b - pressure head loss in bend /m/;

h_{p1-5} - pressure head loss in straight pipe sections
 $L_1 \dots L_2$ /m/

h_c - pressure head loss in pipe couplers /m/

h_{dif} - pressure head loss in diffuser /m/

h_o - pressure head loss in orifice plate /m/

h_{con} - pressure head loss due to converger /m/

h_{pg} - pressure reading in pressure gauge /m/

h_g - pressure addition due to elevation /m/

While,

$$h_b = \sum_b \frac{v^2}{2g} \quad [2]$$

where: $\sum_b$ - bend factor / $\sum_{90^\circ} = 2$, $\sum_{60^\circ} = 1$ /
 v - velocity of water flow /m/s/

$$h_{p1-5} = \lambda \frac{1}{d} \frac{v^2}{2g} \quad [3]$$

Appendix 3.37

Where: λ - friction factor /= 0,03/

l - length of the pipe section /m/

d - diameter of the pipe section /m/

$$h_c = \xi_c \cdot \frac{v^2}{2g} \quad [4]$$

Where: ξ_c - coupler factor / = 0,3/

$$h_{dif} = \xi_{dif} \cdot \frac{v^2}{2g} \quad [5]$$

Where: ξ_{dif} - diffuser factor /= 0,3/

$$h_o = \frac{1 - \alpha^2}{\alpha} \cdot \xi_o \cdot \frac{v^2}{2g} \quad [6]$$

Where: ξ_o - orifice factor / = 1,2/

α - discharge coefficient / = 0,65/

$$h_{con} = \xi_{con} \cdot \frac{v^2}{2g} \quad [7]$$

Where: ξ_{con} - converger factor /= 0,03/

Using equations [2] through [7] for the given five average water discharges, various pressure head loss values were calculated, and putting those in equation 1 respective hydrant pressures were obtained. The calculation results are summarized in Appendix 3.38.

Appendix 3.38

Results of hydrant pressure calculations

Symbol	Average water discharges				
	q_1	q_2	q_3	q_4	q_5
h_b	0,0771	0,0708	0,0606	0,0480	0,0381
h_{p1}	0,0356	0,0327	0,0280	0,0221	0,0176
h_c	0,0231	0,0212	0,0182	0,0144	0,0114
h_{p2}	0,0020	0,0018	0,0016	0,0012	0,0010
h_{dif}	0,0077	0,0071	0,0061	0,0048	0,0038
h_{p3}	0,0061	0,0056	0,0047	0,0037	0,0030
h_o	0,0719	0,0673	0,0563	0,0447	0,0356
h_{p4}	0,0034	0,0032	0,0027	0,0021	0,0017
h_{con}	0,0008	0,0007	0,0006	0,0005	0,0004
h_{p5}	0,0007	0,0006	0,0005	0,0004	0,0003
h_{pg}	34,33	32,77	27,50	22,50	17,50
h_g	1,0	1,0	1,0	1,0	1,0
H_h /m/	33,56	31,98	26,68	21,64	16,61



Appendix 4.1

List of applied symbols for computer programming

Symbol	Description	Unit
A	Power cost, day period	FT/KW
AHL	Allowed Head Loss	M
ACN	Area Covered by one Nozzle	SQM
AIU	Area of Irrigation Unit	HA
B	Power cost, peak period	FT/KW
C	Energy cost, day period	FT/KWH
CPL	Connecting Pipe Length	M
CRF	Capital Recovery Factor	-
D	Energy cost, night period	FT/KWH
DBV	Deviation from the Base Value	-
DCL	Diesel oil energy Cost of Lifting	FT/HA
DDL	Diesel oil energy Demand of Lifting	KG/HA
DEC	Diesel oil Energy Cost of irrigation	FT/HA
DED	Diesel oil Energy Demand of irrigation	KG/HA
DHS	Distance between Hydrants on Submain	M
DNL	Distance between Nozzles on Lateral	M
DOH	Daily Operation Hours	HRS
DSL	Distance between Settings of Lateral	M
* E	Average price of Electricity	FT/KWH
ECL	Electric energy Cost of Lifting	FT/HA
EDL	Electric energy Demand of Lifting	KWH/HA
EEC	Electric Energy Cost of irrigation	FT/HA
EED	Electric Energy Demand	KWH/HA
EIC	Energy supplying Investment Cost	FT
EPD	Electric Power Demand	KW
GHL	Geographical Level of Hydrant	M
HLC	Head Loss in Connecting pipe	M
HLL	Head Loss of Lateral, total	M
IEF	Irrigation Efficiency	PERC
IIL	Irrigation Intensity of Lateral	MM/HA
IRA	Irrigated Area	HA
* DWA	Depth of Water Application	MM

Appendix 4.1

Symbol	Description	Unit
IRP	Irrigation Period	DAYS
IRD	Irrigation Days	DAYS
LIU	Length of Irrigation Unit	M
LMR	Labour, Maintenance, and Repair cost	FT
MEF	Motor Efficiency	PERC
MPL	Main Pipe section Length	M
NIP	Number of Irrigation Period	-
NML	Number of Main Lines	-
NNL	Number of Nozzles on one Lateral	-
NOL	Number of simultaneously Operated Laterals	-
NSL	Number of Submain Lines	-
NSL	Number of Settings of Lateral	-
NWA	Number of irrigation Water Applications	-
NWN	Nominal Water discharge of Nozzle	L/S
NWR	Net water Requirement of Crop	CUM/HA
P	Average Price of diesel oil	FT/KG
PDH	Pressure Demand at Hydrant	M
PDM	Pipe DiaMeter	M
PEF	Pump Efficiency	PERC
PFF	Pipe Friction Factor	-
PHL	Pressure Head Loss of mains and submains	M
PIC	Pumping plant Investment Cost	FT
PIL	Pump Inside Losses of head	M
PLN	Pressure at Last Nozzle	M
PPD	Pump Power Demand	KW
PPDP	Pumping Power Demand, Peak period	KW
PUE	Pumping Unit Efficiency	PERC
PWD	Pipe Water Discharge	CUM/S
PWV	Pipe Water Velocity	M/S
RNT	Ratio of Night Tariff	-
RPD	Ratio of Peak power Demand	-
RWD	Required Water Discharge for irrigation	L/S

Appendix 4.1

Symbol	Description	Unit
RWL	Required Water discharge of Lateral	L/S
SPC	Specific Cost of Pipe	FT/M
SDC	Specific Diesel oil Cost of irrigation	FT/CUM
SDR	Specific Diesel oil Requirement	KG/CUM
SEC	Specific Electric energy Cost of irrigation	FT/CUM
SEC	Specific electric Energy Cost	FT
SED	Specific electric Energy Demand	KWH
SER	Specific Electric energy Requirement	KWH/CUM
SFC	Specific Fuel Consumption	KG/KWH
SHL	Specific Head Loss	M
SIC	Specific Investment Cost	FT
SMC	Specific Mainline investment Cost	FT
SOC	Specific Operation Cost	FT
SPD	Specific electric Power Demand	KW
SPL	Submain Pipe section Length	M
SSC	Specific Submain investment Cost	FT
SWL	Suction Water Level	M
TDD	Total Diesel oil Demand of irrigation	KG/HA
TDH	Total Dynamic Head	M
TEC	Total Electric energy Cost of irrigation	FT/HA
TED	Total Electric energy Demand	KWH/HA
TEF	Transport EFFiciency of canal	PERC
THL	Total Head of Lifting	M
THL	Total Head Loss	M
TIC	Total Investment Cost	FT
TWD	Total Water Discharge	CUM/S
TWI	Total Water discharge Increments of lateral	L/S
TWL	Total Water discharge of one Lateral	L/S
WIC	Water supply Investment Cost	FT
WIU	Width of Irrigation Unit	M

Appendix 4.1

Symbol	Description	Unit
YEC	Yearly Electric energy Cost	FT
YED	Yearly Electric energy Demand	KWH
YOC	Yearly Operation Cost	FT
YOH	Yearly Operation Hours	HRS
YPC	Yearly Pipe-section Cost	FT/M
YTC	Yearly Total Cost of operation of pipe-section	FT

Appendix 4.2

Base input data for computer program of
Model No.1

Input parameters		Irrigation method				
Symbol	Unit	Portable sprinkler	Installed sprinkler	Surface	Sub- surface	Drip
IRA	HA	60	1200	60	60	60
DWA	MM/HA	60	60	80	50	30
IRP	DAYS	18	18	18	18	9
DOH	HRS	18	18	16	18	20
TDH	M	70	75	10	15	15
NWR	CUM/HA	1260	1260	1260	1260	810
IEF	PERC	70	70	60	80	90
PEF1	PERC	65	75	70	70	70
PEF2	PERC	70	70	70	70	70
PUE1	PERC	52	60	56	56	56
PUE2	PERC	60	60	60	60	60
THL	M	6/8/14	6/8/14	6/8/14	6/8/14	6/8/14
TEF	PERC	60/70	60/70	60/70	60/70	60/70
SFC	KG/KWH	0,3	0,3	0,3	0,3	0,3
PPDP	KW	0	0	0	0	0
E	FT/KWH	1,6	1,6	1,6	1,6	1,6
P	FT/KG	10	10	10	10	10
A	FT/KW	270	270	270	270	270
B	FT/KW	750	750	750	750	750
C	FT/KWH	1,3	1,3	1,3	1,3	1,3
D	FT/KWH	0,7	0,7	0,7	0,7	0,7
RNT	PERC	0	0	0	0	0

```

0          MASTER ELEC
1  C      ELECTRICALLY***
2          INTEGER TILT
3          LOGICAL BAZIS
4          DIMENSION B(22),T(10,4),TILT(5,5),E(12),S(22)
5          COMMON /BZ/ B1,B2
6          DATA TILT/21*0,1,3*0/
7          DEFINE FILE (6,75000,81,25)
8          DEFINE FILE (7,80000,45,25)
9          NN=0
10         DO 6 IM=1,5
11         DO 5 IS=1,5
12             NN=0
13             IR=(IS-1)*5+IM
14             FIND(6,IR)
15             READ(6) T
16  C      WRITE(5,2) ((T(K,I),I=1,4),K=1,10)
17  2      FORMAT(1X,4+10.4)
18             FIND(7,IR)
19             READ(7) B
20  C      IF (TILT(IS,IM).EQ.1) GOTO 6
21         DO 7 MI=1,10
22             WRITE(5,654)
23  654     FORMAT(//)
24             IF (T(MI,1).EQ.-999.) GOTO 5
25             IF (MOD(NN,2) EQ.0) CALL F1( IS,IM,B,T(MI,1))
26             NN=NN+1
27             WRITE(5,654)
28             CALL F2(T(MI,1))
29             BAZIS=.TRUE.
30             CALL SZAMUL(BAZIS,B,E,E1)
31             DO 77 M=1,22
32  77      S(M)=B(M)
33             F(9)=B1
34             E(10)=B2
35             C=T(MI,2)
36             IK=T(MI,1)
37  9      S(IK)=C
38             BAZIS=.FALSE.
39             CALL SZAMUL (BAZIS,S,E,C)
40  11     FORMAT( 1H1,9F9.2,F12.2,2F11.2)
41             WRITE(5,10) E
42  10     FORMAT(1X,11F9.2,F11.2)
43             C=C+T(MI,4)
44             IF(C.LE.T(MI,3)) GOTO 9
45         7 CONTINUE
46         5 CONTINUE
47         6 CONTINUE
48         STOP
49         END
50         SUBROUTINE SZAMUL (BAZIS,BS,E,E1)
51         LOGICAL BAZIS
52         DIMENSION BS(22),E(12)
53         COMMON /BZ/ B1,B2
54         RWD=(10.*BS(1)*S(2))/(3.6*BS(3)*BS(4))
55         E(1)=E1
56         F(2)=RWD*BS(5)/(102.*BS(8))
57         F(3)=BS(5)/(367.2*BS(10))
58         F(4)=E(3)*BS(6)/BS(7)
59         E(5)=(BS(10)*F(2)+BS(19)*BS(15))/BS(1)+

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- 2 -

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60      *          F(4)*(BS(20)-BS(22)*(BS(20)-BS(21)))
61      E(6)=F(5)*BS(7)/BS(5)
62      F(7)=(BS(12)*BS(6))/(367.2*BS(11)*BS(7)*BS(13))
63      E(8)=F(7)*BS(16)
64      F(9)=E(4)+E(7)
65      F(10)=E(5)+F(8)
66      IF(BAZIS) GOTO 7
67      F(11)=E(9)-B1
68      E(12)=F(10)-B2
69      RETURN
70  7  B1=E(9)
71      B2=F(10)
72      RETURN
73      END
74      SUBROUTINE F2(T,I)
75      INTEGER SF(22)
76      REAL SA(22)
77      DATA SF/4HIRA ,4HDWA ,4HIRP ,
78      * 4HDOH ,4HTDH ,4HNWR ,4HIEF ,
79      * 4HPEF1,4HPEF2,4HPUE1,4HPUE2,
80      * 4HTHL ,4HTEF ,4HSEC ,4HPPDP,
81      * 4HE ,4HP ,4HA ,4HB ,
82      * 4HC ,4HD ,4HRNT /
83      DATA SA/8H HA ,8H MM ,8H DAYS ,
84      *8H HOURS ,8H M ,8H CUM/HA ,
85      *8H PERC ,8H DEPC ,8H PERC ,
86      *8H PERC ,8H DEPC ,8H PERC ,
87      *8H PERC ,8H Kt/KWH ,8H KJ ,
88      *8H FT/KWH ,8H * ,8H FT/KWH ,
89      *8H FT/KW ,8H FT/KWH ,8H FT/KWH ,
90      *8H PERC /
91      V=1H-
92      WRITE(5,10) (V,I=1,115)
93  10  FORMAT(1X,115A1)
94      M=IFIX(TMI)
95      WRITE(5,20) SF( )
96  20  FORMAT(5X,A4,6X,3HPPD,5X,3HSER,6X,3HEFD,6X,3HEEC,
97      *6X,3HSEC,6X,3HEDL,6X,3HFCL,6X,3HTED,6X,3HTEC,10X,
98      *3HDRV)
99      WRITE(5,40) SA(M)
100  40  FORMAT(2X,A8,4X,2HKW,5X,7HKWH/CUM,2X,6HKWH/HA,
101      *4X,5HFT/HA,4X,6HFT/CUM,2X,6HKWH/HA,4X,5HFT/HA,
102      *4X,6HKWH/HA,3X,5HFT/HA,3X,6HKWH/HA,
103      *4X,5HFT/HA)
104      WRITE(5,10) (V,K=1,115)
105      RETURN
106      END
107      SUBROUTINE F1(I,IS,BV,M)
108      REAL M
109      COMPLEX CS(5,3),CM(5,2)
110      DIMENSION B(22),BV( 22)
111      DATA CS/
112      *16HSURFACE WATER SO,16HIRRIGATION CANAL,16HIRRIGATION CANAL,
113      *16HIRRUGATION CANAL,16HUNDERGROUND WATE,16HURCES BY GRAVITY,
114      *16H BY PRIMARY LIFT,16H BY SECONDARY LI,16H BY TWO STAGE LI,
115      *16HR SOURCES ,16H ,16HING ,
116      *16HFTING ,16HFTING ,16H /
117      DATA CM/
118      *16HPORTABLE SPRINKL,16HINSTALLED SPRINK,16HSURFACE IRRIGATI,
119      *16HSUBSURFACE IRRIG,16HDRIIP IRRIGATION ,16HER IRRIGATION ,

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120      *16HLER IRRIGATION ,16HOW ,16H ,
121      *16H /
122      C      WRITE(5,70) CM
123      C70      FORMAT(1X,5A,,)
124      DO 6 I=1,22
125      6      B(I)=bV(I)
126      M1=IFIX(M)
127      C      B(M1)=9999999.
128      B10=100.*B(10)
129      B11=100.*B(11)
130      B12=B(12)
131      B13=100.*B(13)
132      B22=100.*B(22)
133      B8=100.*B(8)
134      B7=100.*B(7)
135      B9=100.*B(9)
136      WRITE(5,10)
137      10      FORMAT(1H1,/,/,40X,30HENERGY DEMAND AND COST ANALYSIS,
138      *15HS OF IRRIGATION)
139      WRITE(5,20) B(1), B10,B(19)
140      20      FORMAT(/,10X,27HELECTRICALLY OPERATED PUMPS,19X,
141      *4HIRA=,F7.0,3H HA,9X,5HPUE1=,F6.1,5H PERC,9X,
142      *5HB =,F6.1,6H FT/KW)
143      WRITE(5,30) (CS(15,K),K=1,3),B(2), B11,B(20)
144      30      FORMAT(10X,5A8,,5,5H DWA=,F6.1,3H MM,9X,5HPUE2=,
145      *F6.1,5H PERC,9X,5HC =,F6.1,7H FT/KWH)
146      L=IM
147      WRITE(5,40) CM( L,1),CM( L,2),B(3), B12,B(21)
148      40      FORMAT(10X,A8,A^,A8,A8,14X,4HIRP=,F6.1,5H DAYS,7X,5HTHL =,
149      *F6.1,5H M ,9X,5HD =,F6.1,7H FT/KWH)
150      WRITE(5,50) B(4),B13,B22,B(5),B(14)
151      50      FORMAT(56X,4HDOF=,F6.1,4H HRS,8X,4HTTF=,F7.1,5H PERC,9X,
152      *5HRNT =,F6.1,5H PERC,/,56X,4HTDH=,F6.1,4H M ,8X,4HSFC=,
153      *F7.1,7H KG/KWH)
154      WRITE(5,97) A(6),B(15)
155      97      FORMAT(56X,4HWR=,F7.0,7H CUM/HA,4X,5HPPDP=,F6.1,3H KW)
156      WRITE(5,60) B7,B(16),B8,B(17)
157      60      FORMAT(56X,4HIEF=,F6.1,5H PERC,7X,4HE =,F7.1,7H FT/KWH,
158      */,56X,5HPEF1=,F6.1,4HPERC,7X,4HP =,F7.1,6H FT/KG)
159      SPACE=1H
160      WRITE(5,70) B9,B(18),SPACE
161      70      FORMAT(56X,5HPEF2=,F6.1,4HPERC,7X,4HA =,F7.1,6H FT/KW,A1)
162      RETURN
163      END
164      FINISH
165      *****

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0          MASTER MMEL
1  C          DIESEL***
2          INTEGER TILT
3          LOGICAL BAZIS
4          DIMENSION B(22),T(10,4),TILT(5,5),E(12),S(22)
5          COMMON /BZ/ B1,B2
6          DATA TILT/21*0,1,3*/
7          DEFINE FILE (6,75000,81,25)
8          DEFINE FILE (7,40000,45,25)
9          DO 6 IM=1,5
10         DO 5 IS=1,5
11             NN=0
12             IF (TILT(IS,IM).EQ.1) GOTO 5
13             IR=(IM-1)*5+IS
14             FIND(6,IR)
15             READ(6) T
16  C          WRITE(5,2) ((T(K,I),I=1,4),K=1,10)
17  11          FORMAT(//)
18  2          FORMAT(1X,4*10.4)
19             FIND(7,IR)
20             READ(7) B
21             DO 7 MI=1,10
22                 WRITE(5,654)
23  654          FORMAT(//)
24                 IF (T(MI,1).EQ.-999.) GOTO 5
25                 IF (MOD(NN,2).EQ.0) CALL F1(IS,IM,B,T(MI,1))
26                 NN=NN+1
27                 CALL F2(T(MI,1))
28  C          WRITE(5,11)
29             BAZIS=.TRUE.
30             CALL SZAMOL(BAZIS,B,E,E1)
31             DO 77 MI=1,22
32  77          S(MI)=B(MI)
33             F(9)=B1
34             E(10)=B2
35             C=T(MI,2)
36             IK=T(MI,1)
37  9          S(IK)=C
38             BAZIS=.FALSE.
39             CALL SZAMOL(BAZIS,S,E,C)
40             WRITE(5,10) E
41  10          FORMAT(1X,9F9.4,F12.2,2F11.2)
42             C=C+T(MI,4)
43             IF (C.LE.T(MI,3)) GOTO 9
44             7 CONTINUE
45             5 CONTINUE
46             6 CONTINUE
47             STOP
48             END
49             SUBROUTINE SZAMOL (BAZIS,BS,E,E1)
50             LOGICAL BAZIS
51             DIMENSION BS(22),E(12)
52             COMMON /BZ/ B1,B2
53             RWD=(10.*BS(1)*BS(2))/(3.6*BS(3)*BS(4))
54             E(1)=E1
55             E(2)=RWD*BS(5)/(102.*BS(8))
56             E(3)=BS(5)*BS(14)/(367.2*BS(8))
57             E(4)=E(3)*BS(6)/BS(7)
58             E(5)=E(4)*BS(17)
59             E(6)=E(5)*BS(7)/BS(6)

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60      E(7)=BS(12)*BS(6)*BS(14)/(357.2*BS(9)*BS(7)*BS(13))
61      E(8)=E(7)*BS(17)
62      E(9)=E(4)+E(7)
63      E(10)=E(5)+E(8)
64      IF(BAZIS) GOTO 7
65      E(11)=E( 9)-B1
66      E(12)=E( 10)-B2
67      RETURN
68 7 B1=E(9)
69   B2=E(10)
70   RETURN
71   END
72   SUBROUTINE F2(T I)
73   INTEGER SF(22)
74   REAL SA(22)
75   DATA SF/4HIRA ,4HWA ,4HIRP ,
76   * 4HDOH ,4HTDH ,4HNWR ,4HIEF ,
77   * 4HPEF1,4HPEF2,4HPUE1,4HPUE2,
78   * 4HTHL ,4HTFF ,4HSFC ,4HPPDP,
79   * 4HE ,4HP ,4HA ,4HB ,
80   * 4HC ,4HD ,4HRNT /
81   DATA SA/8H HA ,8H MM ,8H DAYS ,
82   *8H HOURS ,8H M ,8H CUM/HA ,
83   *8H PERC ,8H PERC ,8H PERC ,
84   *8H PERC ,8H PERC ,8H PERC ,
85   *8H PERC ,8H K./KWH ,8H KU ,
86   *8H FT/KWH ,8H * ,8H FT/KWH ,
87   *8H FT/KU ,8H FT/KWH ,8H FT/KWH ,
88   *8H PERC /
89   V=1H-
90   WRITE(5,10) (V,I=1,115)
91 10  FORMAT(1X,115A1)
92   M=IFIX(TMI)
93   WRITE(5,20) SF(I)
94 20  FOR'IAT(5X,A4,5X,3HPPD,7X,3HSDR,6X,3HDED,6X,3HDEC,
95   *6X,3HSDC,6X,3HDOL,6X,3HDCL,6X,3HTDD,9X,3HTDC,10X,
96   *3HDVB)
97   WRITE(5,40)SA(M)
98 40  FORMAT(2X,A8,4X,2HKW,5X,7H KG/CUM,2X,6H KG/HA,
99   *4X,5HFT/HA,4X,6H FT/CUM,2X,6H KG/HA,4X,5HFT/HA,
100  *4X,6H KG/HA,6X,5HFT/HA,3X,6H KG/HA,
101  *4X,5HFT/HA)
102   WRITE(5,10)(V,K=1,115)
103   RETURN
104   END
105   SUBROUTINE F1(IS,IM,BV,M)
106   REAL M
107   COMPLEX CS(5,3),CM(5,2)
108   DIMENSION B(22),BV( 22)
109   DATA CS/
110   *16HSURFACE WATER,16HIRRIGATION CANAL,16HIRRIGATION CANAL,
111   *16HIRRIGATION CANAL,16HUNDERGROUND WATER,16HURCES BY GRAVITY,
112   *16H BY PRIMARY LIFT,16H BY SECONDARY LI,16H BY TWO STAGE LI,
113   *16H SOURCES ,16H ,16HING ,
114   *16HFTING ,16HFTING ,16H /
115   DATA CM/
116   *16HPORTABLE SPRINKL,16HINSTALLED SPRINK,16HSURFACE IRRIGATI,
117   *16HSUBSURFACE IRRIG,16HD RIP IRRIGATION ,16HER IRRIGATION ,
118   *16HLER IRRIGATION ,16HON ,16H ,
119   *16H /

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```

120 C      WRITE(5,70)  IM
121 C70    FORMAT(1X,5A~)
122      DO 6 I=1,22
123 6      B(I)=BV(I)
124      MI=IFIX(M)
125 C      B(MI)=9999999.
126      B10=100.*B(10)
127      B11=100.*B(11)
128      B12=B(12)
129      B13=100.*B(13)
130      B22=100.*B(22)
131      B8=100.*B(8)
132      B7=100.*B(7)
133      B9=100.*B(9)
134      WRITE(5,10)
135 10     FOR 11T(1H1,/,/,4X,30HENERGY DEMAND AND COST ANALYSI,
136      *15HS OF IRRIGATION)
137      WRITE(5,20) B(1), B10,B(19)
138 20     FORMAT(/,10X,21HDIESFL OPERATED PUMPS,25X,
139      *4HIRA=,F6.0,3H HA,9X,5HPJE1=,F6.1,5H PERC,9X,
140      *5HB      =,F6.1,6H FT/KJ)
141      WRITE(5,30) (CS(IS,K),K=1,3),B(2), B11,B(20)
142 30     FORMAT(10X,5A8,^5,5H DWA=,F6.1,3H MM,9X,5HPUE2=,
143      *F6.1,5H PERC,9X,5HC      =,F6.1,7H FT/KWH)
144      L=IM
145      WRITE(5,40) CM( L,1),CM( L,2),B(3), B12,B(21)
146 40     FORMAT(10X,A8,A.,A8,A8,14X,4HIRP=,F6.1,5H DAYS,7X,5HTHL =,
147      *F6.1,5H M      ,9X,5HD      =,F6.1,7H FT/KWH)
148      WRITE(5,50) B(4),B13,B22,B(5),B(14)
149 50     FORMAT(56X,4HDUR=,F6.1,4H HRS,8X,4HTEF=,F7.1,5H PERC,9X,
150      *5HRT      =,F6.1,5H PERC,/,56X,4HTDH=,F6.1,4H M      ,8X,4HSFL=,
151      *F7.1,7H KG/KWH)
152      WRITE(5,97) B(6),B(15)
153 97     FORMAT(56X,4HDUR=,F7.0,7H CUM/HA,4X,5HPPDP=,F6.1,3H KW)
154      WRITE(5,60) B7,B(16),B8,B(17)
155 60     FORMAT(56X,4HIEF=,F6.1,5H PERC,7X,4HE      =,F7.1,7H FT/KWH,
156      */,56X,5HPEF1=,F6.1,4HPERC,7X,4HP      =,F7.1,6H FT/KG)
157      SPACE=1H
158      WRITE(5,70) B9,B(18),SPACE
159 70     FORMAT(56X,5HPEF2=,F6.1,4HPERC,7X,4HA      =,F7.1,6H FT/KW,A1)
160      WRITE(5,111)
161 111    FORMAT(//)
162      RETURN
163      END
164      FINISH
165      *****

```

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

ELECTRICALLY OPERATED PUMPS				B = 750.0 FT/KW			
IRRIGATION CANAL BY SECONDARY LIFTING				C = 1.3 FT/KWH			
INSTALLED SPRINKLER IRRIGATION				D = 0.7 FT/KWH			
				RNT = 0.0 PERC			

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

ELECTRICALLY OPERATED PUMPS				IRA= 1200. HA				PUE1= 60.0 PERC				B = 750.0 FT/KW			
IRRIGATION CANAL BY TWO STAGE LIFTING				DWA= 60 0 MM				PUE2= 60 0 PERC				C = 1.3 FT/KWH			
INSTALLED SPRINKLER IRRIGATION				INP= 18.0 DAYS				THL = 14 0 M				D = 0.7 FT/KWH			
				DDH= 18 0 HRS				TEF= 60.0 PERC				RNT = 0.0 PERC			
				TDH= 75 0 M				SEC= 0 0 KG/KWH							
				NWR= 1200 CUM/HA				PPDP= 0 0 KW							
				IEF= 70.0 PERC				E = 1 6 FT/KWH							
				PEF1= 75. PERC				P = 0 0 FT/KG							
				PEF2= 0 PERC				A = 270 0 FT/KW							

NWR	PPD	SER	EED	FFC	SEC	EDL	ECL	TED	TEC	DBV
CUM/HA	KW	KWH/CUM	KWH/HA	FT/HA	FT/CUM	KWH/HA	FT/HA	KWH/HA	FT/HA	FT/HA
420 00	605 18	0.34	204 25	401 69	0 67	63.54	101 67	267.79	503 36	-734 39
630 00	605 18	0.34	306 37	534 45	0 59	95 32	152 51	401 69	686.96	-550 79
840 00	605 18	0.34	408 50	667 21	0 56	127 09	203 34	535 58	870 55	-367 19
1050 00	605 18	0.34	510 62	799 97	0 53	158.86	254 18	669 48	1054 15	-183 60
1260 00	605 18	0.34	612 75	932 73	0 52	190 63	305 01	803 38	1237 75	0.00
1470 00	605.18	0.34	714 87	1065 50	0.51	222 40	355 85	937 27	1421 34	183.60
1680 00	605 18	0.34	816 99	1198 26	0 50	254 18	406 68	1071.17	1604.94	267.79
1890 00	605 18	0.34	919 12	1331 02	0 49	285 95	457 52	1205 07	1788 53	401 69
2100 00	605.18	0.34	1021 24	1463 78	0 49	317 72	508 35	1338.96	1972 13	734 39

PUE2	PPD	SER	EED	EEC	SEC	EDL	ECL	TED	TEC	DBV
PERC	KW	KWH/CUM	KWH/HA	FT/HA	FT/CUM	KWH/HA	FT/HA	KWH/HA	FT/HA	FT/HA
0 50	605 18	0.34	612 75	932 73	0 52	228 76	366 01	841.50	1298 75	38.13
0 52	605 18	0.34	612 75	932 73	0.52	219.96	351 94	832.70	1284 67	29 33
0 54	605 18	0.34	612 75	932 73	0 52	211 81	338 90	824 56	1271.64	21 18
0 56	605 18	0.34	612 75	932 73	0 52	204 75	326 80	816 99	1259 53	13.62
0 58	605 18	0.34	612 75	932 73	0 52	197 71	315 53	809 95	1248 26	6 57
0 60	605 18	0.34	612 75	932 73	0 52	190.63	305 01	803 38	1237 75	0.00
0 62	605 18	0.34	612 75	932 73	0 52	184 48	295 17	797 23	1227 91	-6.15
0 64	605 18	0.34	612 75	932 73	0 52	178.72	285 95	791 46	1218 68	-11 91
0 66	605 18	0.34	612 75	932 73	0 52	173 30	277 28	786 05	1210 02	-17.33
0 68	605 18	0.34	612 75	932 73	0 52	168.20	269 15	780 95	1201.86	-35 88

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

ELECTRICALLY OPERATED PUMPS
IRRIGATION CANAL BY TWO STAGE LIFTING
INSTALLED SPRINKLER IRRIGATION

IRA= 1200 HA
DWA= 60 0 MM
IRP= 18 0 DAYS
DUN= 18 0 HRS
TDH= 75 0 M
NWR= 1200 CUM/HA
IEF= 70 0 PERC
PEF1= 75 0PERC
PEF2= 100 0PERC

PUE1= 60 0 PERC
PUE2= 60 0 PERC
THL = 14 0 M
TEF= 60 0 PERC
SFC= 0 0 KG/KWH
PPDP= 0 0 KW
E = 1 6 FT/KWH
P = 0 0 FT/KG
A = 270 0 FT/KW

B = 750 0 FT/KW
C = 1 3 FT/KWH
D = 0 7 FT/KWH
RNT = 0 0 PERC

THL M	PPD YR	SER KWH/CUM	EED KWH/HA	FEC FT/HA	SEC FT/CUM	EDL KWH/HA	EDL FT/HA	TED KWH/HA	TFC FT/HA	KWH/HA	DBV FT/HA
8 00	605 13	0 34	612 75	932 73	0 52	108 93	174 29	721 68	1107 03	-81 70	-130 72
10 00	605 18	0 34	612 75	932 73	0 52	136 17	217 86	748 91	1150 60	-54 47	-87 15
12 00	605 18	0 34	612 75	932 73	0 52	163 40	261 44	776 14	1194 17	-27 23	-43 57
14 00	605 18	0 34	612 75	932 73	0 52	190 63	305 01	803 38	1237 75	0 00	0 00
16 00	605 18	0 34	612 75	932 73	0 52	217 86	348 58	830 61	1281 32	27 23	43 57
18 00	605 18	0 34	612 75	932 73	0 52	245 10	392 16	857 84	1324 89	54 47	87 15
20 00	605 13	0 34	612 75	932 73	0 52	272 33	435 73	885 08	1368 46	81 70	130 72

TIF PERC	PPD KW	SER KWH/CUM	EED KWH/HA	FFC FT/HA	SEC FT/CUM	EDL KWH/HA	EDL FT/HA	TED KWH/HA	TFC FT/HA	KWH/HA	DBV FT/HA
0 50	605 18	0 34	612 75	932 73	0 52	228 76	366 01	841 50	1298 75	38 13	61 00
0 52	605 18	0 34	612 75	932 73	0 52	219 96	351 94	832 70	1284 67	29 33	46 92
0 54	605 18	0 34	612 75	932 73	0 52	211 81	338 90	824 56	1271 64	21 18	33 89
0 56	605 18	0 34	612 75	932 73	0 52	204 25	326 80	816 99	1259 53	13 62	21 79
0 58	605 18	0 34	612 75	932 73	0 52	197 21	315 53	809 95	1248 26	6 57	10 52
0 60	605 18	0 34	612 75	932 73	0 52	190 63	305 01	803 38	1237 75	0 00	0 00
0 62	605 18	0 34	612 75	932 73	0 52	184 48	295 17	797 23	1227 91	-6 15	-9 84
0 64	605 18	0 34	612 75	932 73	0 52	178 72	285 95	791 46	1218 68	-11 91	-19 06
0 66	605 18	0 34	612 75	932 73	0 52	173 30	277 28	786 05	1210 02	-17 33	-27 73
0 68	605 13	0 34	612 75	932 73	0 52	168 20	269 15	780 95	1201 86	-22 43	-35 88

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

ELECTRICALLY OPERATED PUMPS
IRRIGATION CANAL BY PRIMARY LIFTING
SURFACE IRRIGATION

IRA= 60 HA
DWA= 80 0 MM
IRP= 18 0 DAYS
DUR= 16 0 HRS
TDH= 10 0 M
NHR= 1200 CUM/HA
IEF= 60 0 PERC
PEF1= 70 0 PERC
PEF2= 100 0 PERC

PUE1= 56 0 PERC
PUE2= 60 0 PERC
THL= 6 0 M
TEF= 60 0 PERC
SFC= 1 0 KG/KWH
PPDP= 0 0 KW
E = 1 6 FT/KWH
P = 0 0 FT/KG
A = 270 0 FT/KW

B = 750 0 FT/KW
C = 1.3 FT/KWH
D = 0 7 FT/KWH
RNT = 0 0 PERC

NHR CUM/HA	PPD KW	SER KWH/CUM	EED KWH/HA	EEC FT/HA	SEC FT/CUM	EDL KWH/HA	ECL FT/HA	TED KWH/HA	TEC FT/HA	DBV KWH/HA	FT/HA
420 00	6 48	0 05	34 04	73 43	0 10	31 77	50 84	65 81	124 27	-131 63	-190 18
630 00	6 48	0 05	51 06	95 56	0 09	47 66	76 25	98 72	171 81	-98 72	-142 63
840 00	6 48	0 05	68 08	117 69	0 08	63 54	101 67	131 63	219 36	-65 81	-95 09
1050 00	6 48	0 05	85 10	139 81	0 08	79 43	127 09	164 53	266 90	-32 91	-47 54
1260 00	6 48	0 05	102 12	161 94	0 08	95 32	152 51	197 44	314 45	0 00	0 00
1470 00	6 48	0 05	119 14	184 07	0 08	111 20	177 92	230 35	361 99	32 91	47 54
1680 00	6 48	0 05	136 17	206 19	0 07	127 09	203 34	263 25	409 53	65 81	95 09
1890 00	6 48	0 05	153 19	228 32	0 07	142 97	228 76	296 16	457 08	98 72	142 63
2100 00	6 48	0 05	170 21	250 45	0 07	158 86	254 18	329 07	504 62	131 63	190 18

PUE2 PERC	PPD KW	SER KWH/CUM	EED KWH/HA	EEC FT/HA	SEC FT/CUM	EDL KWH/HA	ECL FT/HA	TED KWH/HA	TEC FT/HA	DBV KWH/HA	FT/HA
0 50	6 48	0 05	102 12	161 94	0 08	114 38	183 01	216 50	344 95	19 06	30 50
0 52	6 48	0 05	102 12	161 94	0 08	109 08	175 97	212 10	337 91	14 66	23 46
0 54	6 48	0 05	102 12	161 94	0 08	105 91	169 45	208 03	331 39	10 59	16 95
0 56	6 48	0 05	102 12	161 94	0 08	102 12	163 40	204 25	325 34	6 81	10 89
0 58	6 48	0 05	102 12	161 94	0 08	98 60	157 76	200 73	319 70	3 29	5 26
0 60	6 48	0 05	102 12	161 94	0 08	95 32	152 51	197 44	314 45	-0 00	-0 00
0 62	6 48	0 05	102 12	161 94	0 08	92 24	147 59	194 37	309 53	-3 07	-4 92
0 64	6 48	0 05	102 12	161 94	0 08	89 36	142 97	191 48	304 91	-5 96	-9 53
0 66	6 48	0 05	102 12	161 94	0 08	86 65	138 64	188 78	300 58	-8 67	-13 86
0 68	6 48	0 05	102 12	161 94	0 08	84 10	134 56	186 23	296 50	-11 21	-17 94

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

ELECTRICALLY OPERATED PUMPS
UNDERGROUND WATER SOURCES
DRIP IRRIGATION

IRA= 60 HA PUE1= 52.0 PERC
DWA= 30.0 MM PUE2= 100.0 PERC
IRP= 9.0 DAYS THL= 0.0 M
DUH= 20.0 HRS TEF= 100.0 PERC
TDH= 25.0 M SFC= 0.0 KG/KWH
NWR= 810 CUM/HA PPDP= 0.0 KW
IEF= 90.0 PERC E= 1.6 FT/KWH
PEF1= 70.0 PERC P= 0.0 FT/KG
PEF2= 100.0 PERC A= 270.0 FT/KW

B = 750.0 FT/KW
C = 1.3 FT/KWH
D = 0.7 FT/KWH
RNT = 0.0 PERC

TDH M	PPD KW	SER KWH/CUM	EED KWH/HA	EEC FT/HA	SEC FT/CUM	EDL KWH/HA	ECL FT/HA	TED KWH/HA	TEC FT/HA	DBV KWH/HA	DBV FT/HA
10.00	3.89	0.05	47.13	78.78	0.09	0.00	0.00	47.13	78.78	-70.70	-118.17
15.00	5.84	0.08	70.70	118.17	0.13	0.00	0.00	70.70	118.17	-47.13	-78.78
20.00	7.78	0.10	94.27	157.56	0.18	0.00	0.00	94.27	157.56	-23.57	-39.39
25.00	9.73	0.13	117.84	196.95	0.22	0.00	0.00	117.84	196.95	0.00	0.00
30.00	11.67	0.16	141.40	236.34	0.26	0.00	0.00	141.40	236.34	23.57	39.39
35.00	13.62	0.18	164.97	275.74	0.31	0.00	0.00	164.97	275.74	47.13	78.78
40.00	15.56	0.21	188.54	315.13	0.35	0.00	0.00	188.54	315.13	70.70	118.17

NWR CUM/HA	PPD KW	SER KWH/CUM	EED KWH/HA	EEC FT/HA	SEC FT/CUM	EDL KWH/HA	ECL FT/HA	TED KWH/HA	TEC FT/HA	DBV KWH/HA	DBV FT/HA
270.00	9.73	0.13	59.28	94.83	0.32	0.00	0.00	59.28	94.83	-78.56	-102.12
540.00	9.73	0.13	78.56	145.89	0.24	0.00	0.00	78.56	145.89	-39.28	-51.06
810.00	9.73	0.13	117.84	196.95	0.22	0.00	0.00	117.84	196.95	0.00	0.00
1080.00	9.73	0.13	157.11	248.02	0.21	0.00	0.00	157.11	248.02	39.28	51.06
1350.00	9.73	0.13	196.39	299.08	0.20	0.00	0.00	196.39	299.08	78.56	102.12
1620.00	9.73	0.13	235.67	350.14	0.19	0.00	0.00	235.67	350.14	117.84	153.19
1890.00	9.73	0.13	274.95	401.20	0.19	0.00	0.00	274.95	401.20	157.11	204.25
2160.00	9.73	0.13	314.23	452.26	0.19	0.00	0.00	314.23	452.26	196.39	255.31

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

FLUORICALLY OPERATED PUMPS
UNDERGROUND WATER SOURCES
DRIP IRRIGATION

IRA= 60 HA
DWA= 30.0 MM
IRP= 9 0 DAYS
DOH= 20 0 HRS
TDH= 25 0 M
HWR= 810 CUM/HA
IEF= 90 0 PERC
PEF1= 70 0PERC
PEF2= 100.0PERC

PUE1= 52.0 PERC
PUE2= 100 0 PERC
THL= 0 0 M
TEF= 100 0 PERC
SEC= 0 0 KG/KUH
PPDP= 0 0 KW
E = 1 6 FT/KWH
P = 0 0 FT/KG
A = 270 0 FT/KW

B = 750 0 FT/KW
C = 1 3 FT/KWH
D = 0 7 FT/KWH
RNT = 0.0 PERC

ILF PERC	PPD KW	SER KWH/CUM	EED KWH/HA	EEC FT/HA	SEC FT/CUM	EDL KWH/HA	ECL FT/HA	TED KWH/HA	TEC FT/HA	KWH/HA	DBV FT/HA
0 80	9 73	0 13	132 57	216 10	0 21	0 00	0 00	132 57	216 10	14 73	19 15
0 82	9 73	0 13	129 33	211 90	0 21	0 00	0 00	129 33	211 90	11 50	14 93
0 84	9 73	0 13	126 25	207 90	0 22	0 00	0 00	126 25	207 90	8 42	10 94
0 86	9 73	0 13	123 32	204 08	0 22	0 00	0 00	123 32	204 08	5 48	7 12
0 88	9 73	0 13	120 51	200 44	0 22	0 00	0 00	120 51	200 44	2 68	3 48
0 90	9 73	0 13	117 84	196 95	0 22	0 00	0 00	117 84	196 95	-0 00	0 00
0 92	9 73	0 13	115 27	193 62	0 22	0 00	0 00	115 27	193 62	-2 56	-3 33

PUE1 PERC	PPD KW	SER KWH/CUM	EED KWH/HA	EEC FT/HA	SFC FT/CUM	EDL KWH/HA	ECL FT/HA	TED KWH/HA	TEC FT/HA	KWH/HA	DBV FT/HA
0 40	9 73	0 17	153 19	242 91	0 27	0 00	0 00	153 19	242 91	35 55	45 96
0 42	9 73	0 16	145 89	233 43	0 26	0 00	0 00	145 89	233 43	28 06	36 47
0 44	9 73	0 15	139 26	224 81	0 25	0 00	0 00	139 26	224 81	21 42	27 85
0 46	9 73	0 15	133 21	216 93	0 24	0 00	0 00	133 21	216 93	15 37	19 98
0 48	9 73	0 14	127 66	209 72	0 23	0 00	0 00	127 66	209 72	9 82	12 77
0 50	9 73	0 14	122 55	203 08	0 23	0 00	0 00	122 55	203 08	4 71	6 13
0 52	9 73	0 13	117 84	196 95	0 22	0 00	0 00	117 84	196 95	0 00	0 00
0 54	9 73	0 13	113 47	191 28	0 21	0 00	0 00	113 47	191 28	-4 36	-5 67
0 56	9 73	0 12	109 42	186 01	0 21	0 00	0 00	109 42	186 01	-8 42	-10 94
0 58	9 73	0 12	105 65	181 11	0 20	0 00	0 00	105 65	181 11	-12 19	-15 85
0 60	9 73	0 11	102 12	176 53	0 20	0 00	0 00	102 12	176 53	-15 71	-20 42

Appendix 4.4

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

DIESEL OPERATED PUMPS
SURFACE WATER SOURCES BY GRAVITY
PORTABLE SPRINKLER IRRIGATION

IRA= 60 HA PUE1= 0 0 PERC B = 0 0 FT/KW
DWA= 60 0 MM PUE2= 0 0 PERC C = 0 0 FT/KWH
IND= 18 0 DAYS TH1 = 0 0 M D = 0 0 FT/KWH
POH= 18 0 HRS SFC= 0 0 PERC RNT = 0 0 PERC
TDH= 70 0 M SFC= 0 3 KG/KWH
NWR= 1260 CUM/HA PPD= 0 0 KW
IEF= 70 0 PERC E = 0 0 FT/KWH
PEF1= 65 ,PERC P = 10 0 FT/KG
PEF2= 0 PERC A = 0 0 FT/KW

IEF PERC	PPD KW	SDR KG/CUM	DFD KG/HA	DEC FT/HA	SDC FT/CUM	DDL KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	DVB KG/HA	FT/HA
0 60	32 59	0 09	184 77	1847 66	0 88	0 00	0 00	184 77	1847 66	26 40	263 95
0 62	32 59	0 09	178 61	1788 06	0 88	0 00	0 00	178 81	1788 06	20 43	204 35
0 64	32 59	0 09	173 22	1732 18	0 88	0 00	0 00	173 22	1732 18	14 85	148 47
0 66	32 59	0 09	167 97	1679 69	0 88	0 00	0 00	167 97	1679 69	9 60	95 98
0 68	32 59	0 09	163 03	1630 29	0 88	0 00	0 00	163 03	1630 29	4 66	46 58
0 70	32 59	0 09	158 37	1583 71	0 88	0 00	0 00	158 37	1583 71	0 00	0 00
0 72	32 59	0 09	153 97	1539 72	0 88	0 00	0 00	153 97	1539 72	-4 40	-43 99
0 74	32 59	0 09	149 81	1498 10	0 88	0 00	0 00	149 81	1498 10	-8 56	-85 61
0 76	32 59	0 09	145 87	1458 68	0 88	0 00	0 00	145 87	1458 68	-12 50	-125 03
0 78	32 59	0 09	142 13	1421 28	0 88	0 00	0 00	142 13	1421 28	-16 24	-162 43

PLF1 PERC	PPD KW	SDR KG/CUM	DFD KG/HA	DEC FT/HA	SDC FT/CUM	DDL KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	DVB KG/HA	FT/HA
0 55	38 51	0 10	187 17	1871 66	1 04	0 00	0 00	187 17	1871 66	28 79	287 95
0 57	37 16	0 10	180 60	1805 99	1 00	0 00	0 00	180 60	1805 99	22 23	222 28
0 59	35 90	0 10	174 48	1744 77	0 97	0 00	0 00	174 48	1744 77	16 11	161 06
0 61	34 72	0 09	168 76	1687 56	0 94	0 00	0 00	168 76	1687 56	10 38	103 85
0 63	33 62	0 09	163 40	1633 99	0 91	0 00	0 00	163 40	1633 99	5 03	50 28
0 65	32 59	0 09	158 37	1583 71	0 88	0 00	0 00	158 37	1583 71	0 00	0 00
0 67	31 61	0 09	153 64	1536 44	0 85	0 00	0 00	153 64	1536 44	-4 73	-47 27
0 69	30 70	0 08	149 19	1491 90	0 83	0 00	0 00	149 19	1491 90	-9 18	-91 81
0 71	29 83	0 08	144 99	1449 88	0 81	0 00	0 00	144 99	1449 88	-13 38	-133 83
0 73	29 07	0 08	141 02	1410 15	0 78	0 00	0 00	141 02	1410 15	-17 36	-173 56

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

DIESEL OPERATED PUMPS									
IRRIGATION CANAL BY SECONDARY LIFTING									
PORTABLE SPRINKLER IRRIGATION									
THL	PPD	SDR	DED	DEC	DDL	DCL	TDD	TDC	DVB
M	W	KG/CUM	KG/HA	FT/HA	KG/HA	FT/HA	KG/HA	FT/HA	FT/HA
5.00	32.59	0.09	158.37	1583.71	0.88	15.43	154.26	173.80	-92.56
6.00	32.59	0.09	158.37	1583.71	0.88	18.51	185.11	176.88	-61.70
7.00	32.59	0.09	158.37	1583.71	0.88	21.60	215.97	179.97	-30.85
8.00	32.59	0.09	158.37	1583.71	0.88	24.68	246.82	183.05	0.00
9.00	32.59	0.09	158.37	1583.71	0.88	27.77	277.67	186.14	30.85
10.00	32.59	0.09	158.37	1583.71	0.88	30.85	308.52	189.22	61.70
11.00	32.59	0.09	158.37	1583.71	0.88	33.94	339.37	192.31	92.56
12.00	32.59	0.09	158.37	1583.71	0.88	37.02	370.23	195.39	123.41

DIESEL OPERATED PUMPS									
IRRIGATION CANAL BY SECONDARY LIFTING									
PORTABLE SPRINKLER IRRIGATION									
THL	PPD	SDR	DED	DEC	DDL	DCL	TDD	TDC	DVB
M	W	KG/CUM	KG/HA	FT/HA	KG/HA	FT/HA	KG/HA	FT/HA	FT/HA
5.00	32.59	0.09	158.37	1583.71	0.88	15.43	154.26	173.80	-92.56
6.00	32.59	0.09	158.37	1583.71	0.88	18.51	185.11	176.88	-61.70
7.00	32.59	0.09	158.37	1583.71	0.88	21.60	215.97	179.97	-30.85
8.00	32.59	0.09	158.37	1583.71	0.88	24.68	246.82	183.05	0.00
9.00	32.59	0.09	158.37	1583.71	0.88	27.77	277.67	186.14	30.85
10.00	32.59	0.09	158.37	1583.71	0.88	30.85	308.52	189.22	61.70
11.00	32.59	0.09	158.37	1583.71	0.88	33.94	339.37	192.31	92.56
12.00	32.59	0.09	158.37	1583.71	0.88	37.02	370.23	195.39	123.41

DIESEL OPERATED PUMPS									
IRRIGATION CANAL BY SECONDARY LIFTING									
PORTABLE SPRINKLER IRRIGATION									
THL	PPD	SDR	DED	DEC	DDL	DCL	TDD	TDC	DVB
M	W	KG/CUM	KG/HA	FT/HA	KG/HA	FT/HA	KG/HA	FT/HA	FT/HA
5.00	32.59	0.09	158.37	1583.71	0.88	15.43	154.26	173.80	-92.56
6.00	32.59	0.09	158.37	1583.71	0.88	18.51	185.11	176.88	-61.70
7.00	32.59	0.09	158.37	1583.71	0.88	21.60	215.97	179.97	-30.85
8.00	32.59	0.09	158.37	1583.71	0.88	24.68	246.82	183.05	0.00
9.00	32.59	0.09	158.37	1583.71	0.88	27.77	277.67	186.14	30.85
10.00	32.59	0.09	158.37	1583.71	0.88	30.85	308.52	189.22	61.70
11.00	32.59	0.09	158.37	1583.71	0.88	33.94	339.37	192.31	92.56
12.00	32.59	0.09	158.37	1583.71	0.88	37.02	370.23	195.39	123.41

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

DIESEL OPERATED PUMPS
UNDERGROUND WATER SOURCES
PORTABLE SPRINKLER IRRIGATION

IRA= 60 HA DWA= 60 0 MM PUE1= 100 0 PERC B = 0.0 FT/KW
IRP= 18.0 DAYS THL= 0 0 M PUE2= 100 0 PERC C = 0.0 FT/KWH
DUH= 18.0 HRS TEF= 100 0 PERC D = 0.0 FT/KWH
TDH= 60.0 M SEC= 0.3 KG/KWH RNT = 0.0 PERC
NWR= 1260 CUM/HA PPDP= 0 0 KW
TEF= 70.0 PERC E = 0 0 FT/KWH
PEF1= 60 0 PERC P = 10 0 FT/KG
PEF2= 100.0 PERC A = 0.0 FT/KW

TDH M	PPD KW	SDR KG/CUM	QED KG/HA	DEC FT/HA	SDC FT/CUM	DDI KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	KG/HA	DVB FT/HA
70 00	35 30	0 10	171 57	1715 69	0 95	0 00	0 00	171 57	1715 69	-24 51	-245 10
72 00	36 31	0 10	175 67	1764 71	0 98	0 00	0 00	176 67	1764 71	-19 61	-196 08
74 00	37 32	0 10	181 37	1813 73	1 01	0 00	0 00	181 37	1813 73	-14 71	-147 06
76 00	38 33	0 10	186 27	1862 75	1 03	0 00	0 00	186 27	1862 75	-9 80	-98 04
78 00	39 34	0 11	191 18	1911 76	1 06	0 00	0 00	191 18	1911 76	-4 90	-49 02
80 00	40 35	0 11	196 08	1960 78	1 09	0 00	0 00	196 08	1960 78	0 00	0 00
82 00	41 35	0 11	200 98	2009 80	1 12	0 00	0 00	200 98	2009 80	4 90	49 02
84 00	42 36	0 11	205 88	2058 82	1 14	0 00	0 00	205 88	2058 82	9 80	98 04
86 00	43 37	0 12	210 78	2107 84	1 17	0 00	0 00	210 78	2107 84	14 71	147 06
88 00	44 38	0 12	215 69	2156 86	1 20	0 00	0 00	215 69	2156 86	19 61	196 08
90 00	45 39	0 12	220 59	2205 88	1 23	0 00	0 00	220 59	2205 88	24 51	245 10
92 00	46 40	0 13	225 49	2254 90	1 25	0 00	0 00	225 49	2254 90	29 41	294 12
94 00	47 41	0 13	230 39	2303 92	1 28	0 00	0 00	230 39	2303 92	34 31	343 14
96 00	48 41	0 13	235 29	2352 94	1 31	0 00	0 00	235 29	2352 94	39 22	392 16
98 00	49 42	0 13	240 20	2401 96	1 33	0 00	0 00	240 20	2401 96	44 12	441 18
100 00	50 43	0 14	245 10	2450 98	1 36	0 00	0 00	245 10	2450 98	49 02	490 20

NWR CUM/HA	PPD KW	SDR KG/CUM	QED KG/HA	DEC FT/HA	SDC FT/CUM	DDL KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	KG/HA	DVB FT/HA
420 00	40 35	0 11	65 36	653 59	1 09	0 00	0 00	65 36	653 59	-130 72	-1307 19
630 00	40 35	0 11	98 04	780 39	1 09	0 00	0 00	98 04	980 39	-98 04	-980 39
840 00	40 35	0 11	130 72	1307 19	1 09	0 00	0 00	130 72	1307 19	-65 36	-653 59
1050 00	40 35	0 11	163 40	1643 99	1 09	0 00	0 00	163 40	1633 99	-32 68	-326 80
1260 00	40 35	0 11	196 08	1960 78	1 09	0 00	0 00	196 08	1960 78	0 00	0 00
1470 00	40 35	0 11	228 76	2287 58	1 09	0 00	0 00	228 76	2287 58	52 68	526 80
1680 00	40 35	0 11	261 44	2614 38	1 09	0 00	0 00	261 44	2614 38	65 36	653 59
1890 00	40 35	0 11	294 12	2941 18	1 09	0 00	0 00	294 12	2941 18	98 04	980 39
2100 00	40 35	0 11	326 80	3267 97	1 09	0 00	0 00	326 80	3267 97	130 72	1307 19

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

DIESEL OPERATED PUMPS
UNDERGROUND WATER SOURCES
PORTABLE SPRINKLER IRRIGATION

IRA= 60 HA DWA= 60 0 MM PUE1= 0 0 PERC B = 0 0 FT/KW
IRP= 18 0 DAYS THL= 0 0 M PUF2= 0 0 PERC C = 0.0 FT/KWH
DOH= 18 0 HRS TEF= 0 0 PERC D = 0 0 FT/KWH
TDH= 40 0 M SFC= 0 3 KG/KWH RNT = 0 0 PERC
NWR= 1260 CUM/HA PPDP= 0 0 KW
IEF= 70.0 PERC E = 0 0 FT/KWH
PEF1= 60 UPERC P = 10.0 FT/KG
PEF2= 0 OPERC A = 0 0 FT/KW

IEF PERC	PPD KW	SOR KG/CUM	DED KG/HA	DEL FT/HA	SDC FT/CUM	DDL KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	KG/HA	DVB FT/HA
0 60	40 35	0 11	228 76	2287 58	1 09	0 00	0 00	228 76	2287 58	32 68	326 80
0 62	40 35	0 11	221 38	2213 79	1 09	0 00	0 00	221 38	2213 79	25 30	253 00
0 64	40 35	0 11	214 46	2144 61	1 09	0 00	0 00	214 46	2144 61	18 38	183 82
0 66	40 35	0 11	207 76	2079 62	1 09	0 00	0 00	207 96	2079 62	11 88	118 84
0 68	40 35	0 11	201 85	2018 45	1 09	0 00	0 00	201 85	2018 45	5 77	57 67
0 70	40 35	0 11	196 08	1960 78	1 09	0 00	0 00	196 08	1960 78	-0 00	-0 00
0 72	40 35	0 11	190 63	1906 32	1 09	0 00	0 00	190 63	1906 32	-5 45	-54 47
0 74	40 35	0 11	185 48	1854 80	1 09	0 00	0 00	185 48	1854 80	-10 60	-105 99
0 76	40 35	0 11	180 60	1805 99	1 09	0 00	0 00	180 60	1805 99	-15 48	-154 80
0 78	40 35	0 11	175 97	1759 68	1 09	0 00	0 00	175 97	1759 68	-20 11	-201 11

PEF1 PERC	PPD KW	SOR KG/CUM	DED KG/HA	DEL FT/HA	SDC FT/CUM	DDI KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	KG/HA	DVB FT/HA
0 50	44 41	0 13	235 29	2352 94	1 31	0 00	0 00	235 29	2352 94	39 22	392 16
0 52	46 55	0 13	226 24	2262 44	1 26	0 00	0 00	226 24	2262 44	30 17	301 66
0 54	44 83	0 12	217 86	2176 65	1 21	0 00	0 00	217 86	2178 65	21 79	217 86
0 56	43 23	0 12	210 08	2100 84	1 17	0 00	0 00	210 08	2100 84	14 01	140 06
0 58	41 74	0 11	202 84	2028 40	1 13	0 00	0 00	202 84	2028 40	6 76	67 61
0 60	40 35	0 11	196 08	1960 78	1 09	0 00	0 00	196 08	1960 78	-0 00	-0 00
0 62	39 04	0 11	189 75	1897 53	1 05	0 00	0 00	189 75	1897 53	-6 33	-65 25
0 64	37 82	0 10	183 82	1838 24	1 02	0 00	0 00	183 82	1838 24	-12 25	-122 55
0 66	36 66	0 10	178 25	1782 53	0 99	0 00	0 00	178 25	1782 53	-17 83	-178 25
0 68	35 60	0 10	173 01	1730 10	0 96	0 00	0 00	173 01	1730 10	-23 07	-230 68

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

DIESFL OPERATED PUMPS
SURFACE WATER SOURCES BY GRAVITY
SURFACE IRRIGATION

IRA= 60 HA
DWA= 80 0 MM
IRP= 18 0 DAYS
DUH= 16 0 HRS
TDH= 10 0 M
IWR= 1200 CUM/HA
IEF= 60 0 PERC
PEF1= 70.0PERC
PEF2= 100.0PERC

PUE1= 100 0 PERC
PUE2= 100.0 PERC
THL= 0 0 M
TEF= 100 0 PERC
SFC= 0 3 KG/KWH
PPDP= 0 0 KW
E= 0 0 FT/KWH
P= 10 0 FT/KG
A= 0 0 FT/KW

B= 0 0 FT/KW
C= 0.0 FT/KWH
D= 0.0 FT/KWH
RNT= 0 0 PERC

PEF1 PERC	PPD KW	SOR KG/CUM	DED KG/HA	DEC FT/HA	SDC FT/CUM	DDL KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	DVB KG/HA	DVB FT/HA
0 50	9 06	0 12	34 51	545 14	0 16	0 00	0 00	34 51	543 14	9 80	98.04
0 52	8 75	0 02	52 77	329 94	0 16	0 00	0 00	32 99	529 94	8 48	84 84
0 54	8 41	0 02	51 77	317 72	0 15	0 00	0 00	31 77	317 72	7 26	72.62
0 56	8 11	0 01	30 64	306 57	0 15	0 00	0 00	30 64	306 57	6 13	61.27
0 58	7 83	0 01	29 54	295 41	0 14	0 00	0 00	29 58	295 41	5 07	50.71
0 60	7 56	0 01	28 59	285 95	0 14	0 00	0 00	28 59	285 95	4 08	40.85
0 62	7 32	0 01	27 67	276 72	0 13	0 00	0 00	27 67	276 72	3 16	31.63
0 64	7 09	0 01	26 81	268 08	0 13	0 00	0 00	26 81	268 08	2 30	22 98
0 66	6 78	0 01	25 00	259 95	0 12	0 00	0 00	25 00	259 95	1 49	14 85
0 68	6 67	0 01	25 23	252 51	0 12	0 00	0 00	25 23	252 51	0 72	7 21
0 70	6 49	0 01	24 51	245 10	0 12	0 00	0 00	24 51	245 10	-0 00	-0 00
0 72	6 30	0 01	23 45	238 29	0 11	0 00	0 00	23 83	238 29	-0 68	-6 81
0 74	6 13	0 01	23 18	231 85	0 11	0 00	0 00	23 18	231 85	-1 32	-13.25
0 76	5 07	0 01	22 57	225 75	0 11	0 00	0 00	22 57	225 75	-1 93	-19.35
0 78	5 82	0 01	22 00	219 96	0 10	0 00	0 00	22 00	219 96	-2 51	-25 14

SFC KG/KWH	PPD KW	SDR KG/CUM	DED KG/HA	DFC FT/HA	SDL FT/CUM	DDL KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	DVB KG/HA	DVB FT/HA
0 20	6 48	0 01	15 54	163 40	0 08	0 00	0 00	16 54	163 40	-8 17	-81 70
0 22	6 48	0 01	17 97	179 74	0 09	0 00	0 00	17 97	179 74	-6 54	-65.36
0 24	6 48	0 01	19 61	196 08	0 09	0 00	0 00	19 61	196 08	-4 90	-49 02
0 26	6 48	0 01	21 24	212 42	0 10	0 00	0 00	21 24	212 42	-3 27	-32 68
0 28	6 48	0 01	22 88	228 76	0 11	0 00	0 00	22 88	228 76	-1 63	-16 34
0 30	6 48	0 01	24 51	245 10	0 12	0 00	0 00	24 51	245 10	-0 00	-0 00
0 32	6 48	0 01	26 14	261 44	0 12	0 00	0 00	26 14	261 44	1 63	16.54
0 34	6 48	0 01	27 78	277 78	0 13	0 00	0 00	27 78	277 78	3 27	32 68
0 36	6 48	0 01	29 41	294 12	0 14	0 00	0 00	29 41	294 12	4 90	49.02
0 38	6 48	0 01	31 05	310 46	0 15	0 00	0 00	31 05	310 46	6 54	65 36
0 40	6 48	0 02	32 68	326 80	0 16	0 00	0 00	32 68	326 80	8 17	81 70

ENERGY DEMAND AND COST ANALYSIS OF IRRIGATION

DIETFL OPERATED PUMPS
SURFACE WATER SOURCES BY GRAVITY
DRIP IRRIGATION

IRA= 60. HA
DWA= 30.0 MM
IRP= 9.0 DAYS
DOH= 20.0 HRS
TDH= 15.0 M
NWR= 810 CUM/HA
IEF= 90.0 PERC
PEF1= 70.0 PERC
PEF2= 100.0 PERC

PUE1= 100.0 PERC
PUE2= 100.0 PERC
THL= 0.0 M
TEF= 100.0 PERC
SFC= 0.3 KG/KWH
PPDP= 0.0 KW
E= 0.0 FT/KWH
P= 10.0 FT/KG
A= 0.0 FT/KW

B= 0.0 FT/KW
C= 0.0 FT/KWH
D= 0.0 FT/KWH
RNT= 0.0 PERC

ILF PERI	PPD KW	SDP KG/CUM	DFD KG/HA	DFC FT/HA	SDC FT/CUM	DDI KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	DVB KG/HA	DVB FT/HA
0.80	5.84	0.02	17.73	177.26	0.18	0.00	0.00	17.73	177.26	1.97	19.70
0.82	5.84	0.02	17.29	172.94	0.18	0.00	0.00	17.29	172.94	1.54	15.37
0.84	5.84	0.02	16.84	168.82	0.18	0.00	0.00	16.88	168.82	1.13	11.25
0.86	5.84	0.02	16.49	164.89	0.18	0.00	0.00	16.49	164.89	0.73	7.33
0.88	5.84	0.02	16.11	161.14	0.18	0.00	0.00	16.11	161.14	0.36	3.58
0.90	5.84	0.02	15.76	157.56	0.18	0.00	0.00	15.76	157.56	-0.00	0.00
0.92	5.84	0.02	15.41	154.14	0.18	0.00	0.00	15.41	154.14	-0.34	-3.43

SFC KG/KWH	PPD KW	SDP KG/CUM	DED KG/HA	DEC FT/HA	SDC FT/CUM	DDL KG/HA	DCL FT/HA	TDD KG/HA	TDC FT/HA	DVB KG/HA	DVB FT/HA
0.20	5.84	0.01	10.50	105.04	0.17	0.00	0.00	10.50	105.04	-5.25	-52.52
0.22	5.84	0.01	11.55	115.55	0.13	0.00	0.00	11.55	115.55	-4.20	-42.02
0.24	5.84	0.01	12.61	126.05	0.14	0.00	0.00	12.61	126.05	-3.15	-31.51
0.26	5.84	0.02	13.66	136.55	0.15	0.00	0.00	13.66	136.55	-2.10	-21.01
0.28	5.84	0.02	14.71	147.06	0.16	0.00	0.00	14.71	147.06	-1.05	-10.50
0.30	5.84	0.02	15.76	157.56	0.18	0.00	0.00	15.76	157.56	-0.00	-0.00
0.32	5.84	0.02	16.81	168.07	0.19	0.00	0.00	16.81	168.07	1.05	10.50
0.34	5.84	0.02	17.86	178.57	0.20	0.00	0.00	17.86	178.57	2.10	21.01
0.36	5.84	0.02	18.91	189.08	0.21	0.00	0.00	18.91	189.08	3.15	31.51

Appendix 4.5

Input parameters for computer program
of Model No. 2

Diameters and specific cost of pipes

Pipe material	Diameter PDM M	Specific cost SPC Ft/M
Asbestos	0,080	115,70
cement	0,100	140,00
	0,125	167,90
	0,150	191,30
	0,200	276,60
	0,250	388,00
	0,300	568,00
	0,400	986,00
	0,500	1533,00
	0,600	2120,00

Capital recovery factor /CRF/

Interest /I/ per cent	Life cycle /N/ in years					
	7	10	15	20	30	40
10	0,205	0,163	0,132	0,118	0,106	0,102
15	0,240	0,199	0,171	0,160	0,152	0,151
20	0,277	0,239	0,214	0,205	0,201	0,200
25	0,316	0,280	0,259	0,253	0,250	0,250

Computer programme for Model No.2

```

0      MASTER VIPD
1      INTEGER DIMPDM
2      (COMPLEX MAT
3      LOGICAL ELSO
4      DIMENSION PDM(15),SPC(15),WPDM(5),WYED(5),WYEC(5)
5      COMMON MAT
6      READ(1,3)MAT,PFF,DIMPDM
7 3     FORMAT(2A8/F0.0,IU)
8      READ(1,4)(PDM(I),SPC(I),I=1,DIMPDM)
9 4     FORMAT(2F0.0)
10     WRITE(3,5) MAT
11 5     FORMAT(2A8)
12     DO 100 IYOH=500,2500,500
13     E=0.
14     IK=0
15     PWD=0.
16     PWHAT=0.25
17     ELSO=.TRUE.
18 1200  CALL FEJ(IYOH,ELSO)
19 1100  F=E+0.3
20     IF(E.GT.6.1) GO TO 109
21 2100  IK=IK+1
22  C    IF(.NOT.ELSO) WRITE(3,98) IK
23 98    FORMAT(I5)
24     PWD=PWD+0.05
25     IF(PWD.GT.PWHAT+0.01) GO TO 2000
26     XMIN=9999999.
27     DO 200 IW=1,DIMPDM
28     APDM=PDM(IW)
29     PWV=1.27* PWD/(APDM**2)
30     IF(PWV.LT.0.5.00.PWV.GT.2.5) GO TO 200
31     SHL=.0021*PFF*(PWD**1.85)*(APDM**(-4.86))
32     EPD=PWD*SHL*1000./(102.*.7*.8)
33     YED=EPD*FLUAT(IYOH)
34     YEC=YED+E
35     YPC=.132*SPC(IW)
36     YTC=YEC+YPC
37     IF(XMIN.LT.YTC) GO TO 200
38     XMIN=YTC
39     PDMW=APDM
40     YEDW=YED
41     YECW=YEC
42 200   CONTINUE
43     UPDM(IK)=PDMW
44     WYED(IK)=YEDW
45     WYEC(IK)=YECW
46     GO TO 2100
47 2000  CONTINUE
48     WRITE(5,10) E,(PDM(I),WYED(I),WYEC(I),I=1,5)
49 10    FORMAT(2X,F5.2,5(F6.2,F7.2,F7.2))
50     IK=0
51     PWD=0.
52     IF(.NOT.ELSO) PWD=0.3
53     GO TO 1100
54 109   IF(.NOT.ELSO) GOTO 100
55     PWHAT=0.5
56     PWD=0.3
57     E=0.
58     IK=0

```

```

60      GO TO 1200
61 100   CONTINUE
62      STOP 34
63      END
64      SUBROUTINE FEJ(IYOH,ELSO)
65      COMPLEX MAT,SS,FF
66      LOGICAL ELSO
67      DIMENSION L( 118)
68      COMMON IAT
69      DATA CUM/5HCUM/5/
70      DATA FF/16HPDM* YED YEC/,SS/16H M KWH FT/
71      WRITE(3,5) MAT
72 5      FORMAT(2A8)
73      DO 3 I=1,118
74 3      L( I)=1H-
75      IF(.NOT.ELSO) GO TO 10
76      WRITE(5,20) MAT,IYOH
77 20     FORMAT(1H1,///,26X,30HTHE OPTIMUM VALUE OF IRRIGATION,
78      *22H PIPE DIAMETER /PDM*///,
79      *24X,30HYEARLY ENERGY DEMAND /YED/ AND,
80      *25H YEARLY ENERGY COST /YEC/,/,
81      *90X,9HMATERIAL-,2A8,///,
82      *90X,4HYOH=,I6,3HRS)
83      WRITE( 5,4) L
84 4      FORMAT( 1X,118A1)
85      WRITE(5,30) (CU,K=1,5)
86 30     FORMAT(1X,8HFW PRICE,5X,5H0.05 ,
87      *A5,10X,5H0.10 ,A5,10X,5H0.15 ,A5,
88      *10X,5H0.20 ,A5,10X,5H0.25 ,A5)
89      WRITE(5,50) (FF,K=1,5),(SS,K=1,5)
90 50     FORMAT( /,4X,1HE,5X,5(2A8,4X),/,
91      *2X,6HFT/KWH,2X,5(2A8,4X))
92      WRITE( 5,4) L
93  C      WRITE(5,666)
94 666     FORMAT(//)
95      RETURN
96 10      WRITE(5,666)
97      WRITE(5,40) (CU,K=1,5)
98 40     FORMAT(13X,5H0.30 ,A5,10X,5H0.35 ,A5,
99      *10X,5H0.40 ,A5,10X,5H0.45 ,A5,
100      *10X,5H0.50 ,A5)
101      WRITE(5,6)
102 6      FORMAT(/)
103      RETURN
104      FND
105      FINISH
106      FILLER
107 6)
108      SUBROUTINE FFJ2(IYOH,ELSO)
109      LOGICAL ELSO
110      COMPLEX MAT
111      DIMENSION IS(5),IA(5),C(10)
112      COMMON MAT
113      DATA CUM/5HCUM/5/
114      DATA IS/4HPDM*,4H ,4HS4L ,4H Y,2HTC/,
115      IA/4H H ,4H M,4H/100,4HM ,2HFT/
116      C(1)=0.05
117      DO 63 I=2,10
118 63     C(I)=C(I-1)+0.05
119      WRITE(5,20) MAT,IYOH

```

Results of computer programming for Model No.2

THE SPECIFIC HEADLOS/SHL / BELONGING TO OPTIMUM VALUE OF /PDM*/
AND YEARLY TOTAL COST /YTC/

MATERIAL										ASB.CEM.									
YOUNG										50UHKS									
0 05 CUM/S										0 20 CUM/S									
J.10 CUM/S										0 40 CUM/S									
0 05 CUM/S										0 50 CUM/S									
0 05 CUM/S										0 50 CUM/S									
0 05 CUM/S										0 50 CUM/S									
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THE OPTIMUM VALUE OF IRRIGATION PIPE DIAMETER /PDM*/
YEARLY ENERGY DEMAND /YED/ AND YEARLY ENERGY COST /YEC/

MATERIAL. ASB CEM.

EN PRICE		0 05 CUM/S				0 10 CUM/S				0 15 CUM/S				0 20 CUM/S				0 25 CUM/S				50HRS			
		E	PDM*	VED	YEC	E	PDM*	VED	YEC	E	PDM*	VED	YEC	E	PDM*	VED	YEC	E	PDM*	VED	YEC	E	PDM*	VED	YEC
FT/KWH	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	
0 30	0 20	6 29	1 89	0 25	15 33	4 60	0 30	20 07	6 02	0 40	11 26	3 58	0 40	21 26	6 38	0 40	21 26	6 38	0 40	21 26	6 38	0 40	21 26	6 38	
0 60	0 20	6 29	3 77	0 25	15 33	9 20	0 30	20 07	12 04	0 40	11 26	6 75	0 40	21 26	12 76	0 40	21 26	12 76	0 40	21 26	12 76	0 40	21 26	12 76	
0 90	0 20	6 29	5 66	0 25	15 33	13 80	0 30	20 07	18 06	0 40	11 26	10 15	0 40	21 26	19 14	0 40	21 26	19 14	0 40	21 26	19 14	0 40	21 26	19 14	
1 20	0 20	6 29	7 55	0 25	15 33	18 39	0 30	20 07	24 08	0 40	11 26	13 51	0 40	21 26	25 52	0 40	21 26	25 52	0 40	21 26	25 52	0 40	21 26	25 52	
1 50	0 20	6 29	9 43	0 25	15 33	22 99	0 30	20 07	30 11	0 40	11 26	16 89	0 40	21 26	31 89	0 40	21 26	31 89	0 40	21 26	31 89	0 40	21 26	31 89	
1 80	0 20	6 29	11 32	0 25	15 33	27 59	0 30	20 07	36 13	0 40	11 26	20 26	0 40	21 26	38 27	0 40	21 26	38 27	0 40	21 26	38 27	0 40	21 26	38 27	
2 10	0 20	6 29	13 21	0 25	15 33	32 19	0 30	20 07	42 15	0 40	11 26	23 64	0 40	21 26	44 65	0 40	21 26	44 65	0 40	21 26	44 65	0 40	21 26	44 65	
2 40	0 20	6 29	15 09	0 25	15 33	36 79	0 30	20 07	48 17	0 40	11 26	27 02	0 40	21 26	51 03	0 40	21 26	51 03	0 40	21 26	51 03	0 40	21 26	51 03	
2 70	0 20	6 29	16 98	0 30	6 52	17 06	0 30	20 07	54 19	0 40	11 26	30 39	0 40	21 26	57 41	0 40	21 26	57 41	0 40	21 26	57 41	0 40	21 26	57 41	
3 00	0 20	6 29	18 87	0 30	6 52	18 96	0 30	20 07	60 21	0 40	11 26	33 77	0 40	21 26	63 79	0 40	21 26	63 79	0 40	21 26	63 79	0 40	21 26	63 79	
3 30	0 20	6 29	20 75	0 30	6 52	20 85	0 30	20 07	66 23	0 40	11 26	37 15	0 40	21 26	70 17	0 40	21 26	70 17	0 40	21 26	70 17	0 40	21 26	70 17	
3 60	0 25	2 13	7 65	0 30	6 32	22 75	0 30	20 07	72 25	0 40	11 26	40 53	0 40	21 26	76 55	0 40	21 26	76 55	0 40	21 26	76 55	0 40	21 26	76 55	
3 90	0 25	2 13	8 29	0 30	6 32	24 65	0 40	4 96	19 34	0 40	11 26	43 90	0 40	21 26	82 92	0 40	21 26	82 92	0 40	21 26	82 92	0 40	21 26	82 92	
4 20	0 25	2 13	8 93	0 30	6 32	26 54	0 40	4 96	20 83	0 40	11 26	47 28	0 40	21 26	89 30	0 40	21 26	89 30	0 40	21 26	89 30	0 40	21 26	89 30	
4 50	0 25	2 13	9 57	0 30	6 52	28 44	0 40	4 96	22 51	0 40	11 26	50 66	0 40	21 26	95 68	0 40	21 26	95 68	0 40	21 26	95 68	0 40	21 26	95 68	
4 80	0 25	2 13	10 21	0 30	6 32	30 33	0 40	4 96	23 80	0 40	11 26	54 05	0 40	21 26	102 06	0 40	21 26	102 06	0 40	21 26	102 06	0 40	21 26	102 06	
5 10	0 25	2 13	10 84	0 30	6 52	32 23	0 40	4 96	25 29	0 40	11 26	57 41	0 40	21 26	108 44	0 40	21 26	108 44	0 40	21 26	108 44	0 40	21 26	108 44	
5 40	0 25	2 13	11 48	0 30	6 52	34 13	0 40	4 96	26 78	0 40	11 26	60 79	0 50	7 19	58 82	0 50	7 19	58 82	0 50	7 19	58 82	0 50	7 19	58 82	
5 70	0 25	2 13	12 12	0 30	6 52	36 02	0 40	4 96	28 26	0 40	11 26	64 16	0 50	7 19	64 97	0 50	7 19	64 97	0 50	7 19	64 97	0 50	7 19	64 97	
6 00	0 25	2 13	12 76	0 30	6 52	37 92	0 40	4 96	29 75	0 40	11 26	67 54	0 50	7 19	71 43	0 50	7 19	71 43	0 50	7 19	71 43	0 50	7 19	71 43	

THE SPECIFIC HEADLOS³SHL / BELONGING TO OPTIMUM VALUE OF /PDM*/
AND YEARLY TOTAL COST /YTC/

EN,PRICE		0 05 CUM/S				0 10 CUM/S				0 15 CUM/S				0 20 CUM/S				0 25 CUM/S				YOH= 1500HRS																			
		PDM*				PDM*				PDM*				PDM*				PDM*				MATERIAL																			
		SHL	YTC	SHL	YTC	SHL	YTC	SHL	YTC	SHL	YTC	SHL	YTC	SHL	YTC	SHL	YTC	SHL	YTC	SHL	YTC	ASB.CEM.																			
E	FT/KWH	M	FT	M	FT	M	FT	M	FT	M	FT	M	FT	M	FT	M	FT	M	FT	M	FT																				
0 50	0 20	0 0144	42.13	0 25	0 0175	65 01	0 30	0 0153	93 04	0 40	0 0064	140 28	0 40	0 0097	149.29	0 40	0 0064	140 28	0 40	0 0097	149.29	0 40	0 0097	149.29																	
0 60	0 20	0 0144	47 79	0 25	0 0175	78 81	0 30	0 0153	111.10	0 40	0 0064	150 41	0 40	0 0097	168.42	0 40	0 0064	150 41	0 40	0 0097	168.42	0 40	0 0097	168.42																	
0 90	0 20	0 0144	53.45	0 30	0 0072	92 04	0 30	0 0153	129.17	0 40	0 0064	160 55	0 40	0 0097	187 56	0 40	0 0064	160 55	0 40	0 0097	187 56	0 40	0 0097	187 56																	
1 20	0 25	0 0049	58 87	0 30	0 0072	97 73	0 30	0 0153	147 25	0 40	0 0064	170 68	0 40	0 0097	206 70	0 40	0 0064	170 68	0 40	0 0097	206 70	0 40	0 0097	206 70																	
1 50	0 25	0 0049	60 78	0 30	0 0072	103.41	0 40	0 0038	152 47	0 40	0 0064	180 81	0 40	0 0097	225 83	0 40	0 0064	180 81	0 40	0 0097	225 83	0 40	0 0097	225 83																	
1 80	0 25	0 0049	62 70	0 30	0 0072	109 10	0 40	0 0038	156.93	0 40	0 0064	190.94	0 40	0 0097	241.17	0 40	0 0064	190.94	0 40	0 0097	241.17	0 40	0 0097	241.17																	
2 10	0 25	0 0049	64 61	0 30	0 0072	114 79	0 40	0 0038	161 39	0 40	0 0064	201 07	0 40	0 0097	267 64	0 40	0 0064	201 07	0 40	0 0097	267 64	0 40	0 0097	267 64																	
2 40	0 25	0 0049	66.52	0 30	0 0072	120 48	0 40	0 0038	165 85	0 40	0 0064	211 20	0 40	0 0097	283 11	0 40	0 0064	211 20	0 40	0 0097	283 11	0 40	0 0097	283 11																	
2 70	0 25	0 0049	68 44	0 30	0 0072	126 16	0 40	0 0038	170 32	0 40	0 0064	221 33	0 40	0 0097	304 58	0 40	0 0064	221 33	0 40	0 0097	304 58	0 40	0 0097	304 58																	
3 00	0 25	0 0049	70 35	0 30	0 0072	131 85	0 40	0 0038	174 76	0 40	0 0064	231 47	0 40	0 0097	326 05	0 40	0 0064	231 47	0 40	0 0097	326 05	0 40	0 0097	326 05																	
3 30	0 25	0 0049	72.26	0 30	0 0072	137 54	0 40	0 0038	179.24	0 40	0 0064	241 60	0 40	0 0097	347 32	0 40	0 0064	241 60	0 40	0 0097	347 32	0 40	0 0097	347 32																	
3 60	0 25	0 0049	74 18	0 30	0 0072	143 23	0 40	0 0038	183.70	0 40	0 0064	251 73	0 40	0 0097	368 60	0 40	0 0064	251 73	0 40	0 0097	368 60	0 40	0 0097	368 60																	
3 90	0 25	0 0049	76 09	0 40	0 0018	148 42	0 40	0 0038	188 17	0 40	0 0064	261 86	0 40	0 0097	389 88	0 40	0 0064	261 86	0 40	0 0097	389 88	0 40	0 0097	389 88																	
4 20	0 25	0 0049	78 00	0 40	0 0018	149 82	0 40	0 0038	192 63	0 40	0 0064	271 99	0 40	0 0097	411 16	0 40	0 0064	271 99	0 40	0 0097	411 16	0 40	0 0097	411 16																	
4 50	0 25	0 0049	79 92	0 40	0 0018	151 23	0 40	0 0038	197 09	0 40	0 0064	282 12	0 40	0 0097	432 44	0 40	0 0064	282 12	0 40	0 0097	432 44	0 40	0 0097	432 44																	
4 80	0 25	0 0049	81 83	0 40	0 0018	152 63	0 40	0 0038	201 55	0 40	0 0064	292 25	0 40	0 0097	453 72	0 40	0 0064	292 25	0 40	0 0097	453 72	0 40	0 0097	453 72																	
5 10	0 25	0 0049	83 74	0 40	0 0018	154 04	0 40	0 0038	206 02	0 40	0 0064	302 38	0 40	0 0097	475 00	0 40	0 0064	302 38	0 40	0 0097	475 00	0 40	0 0097	475 00																	
5 40	0 25	0 0049	85 66	0 40	0 0018	155 45	0 40	0 0038	210 48	0 40	0 0064	312 51	0 40	0 0097	496 28	0 40	0 0064	312 51	0 40	0 0097	496 28	0 40	0 0097	496 28																	
5 70	0 25	0 0049	87 57	0 40	0 0018	156 85	0 40	0 0038	214 94	0 40	0 0064	322 64	0 40	0 0097	517 56	0 40	0 0064	322 64	0 40	0 0097	517 56	0 40	0 0097	517 56																	
6 00	0 25	0 0049	89 49	0 40	0 0018	158 26	0 40	0 0038	219 40	0 40	0 0064	332 77	0 40	0 0097	538 88	0 40	0 0064	332 77	0 40	0 0097	538 88	0 40	0 0097	538 88																	
																						0 30 CUM/S				0 35 CUM/S				0 40 CUM/S				0 45 CUM/S				0 50 CUM/S			
0 30	0 50	0 0061	219 23	0 50	0 0078	227 05	0 50	0 0097	236 90	0 60	0 0049	299 07	0 50	0 0033	331.75	0 50	0 0033	299 07	0 50	0 0033	331.75	0 50	0 0033	331.75																	
0 60	0 50	0 0061	236 11	0 50	0 0078	251 75	0 50	0 0097	271.45	0 60	0 0049	318 30	0 50	0 0033	357.75	0 50	0 0033	318 30	0 50	0 0033	357.75	0 50	0 0033	357.75																	
0 90	0 50	0 0061	252 99	0 50	0 0078	276 44	0 50	0 0097	306 00	0 60	0 0049	337 53	0 50	0 0033	383.75	0 50	0 0033	337 53	0 50	0 0033	383.75	0 50	0 0033	383.75																	
1 20	0 50	0 0061	269 87	0 50	0 0078	301 14	0 60	0 0049	336 81	0 60	0 0049	356 76	0 50	0 0033	409.75	0 50	0 0033	356 76	0 50	0 0033	409.75	0 50	0 0033	409.75																	
1 50	0 50	0 0061	286 75	0 50	0 0078	325 83	0 60	0 0049	355 05	0 60	0 0049	375 99	0 50	0 0033	432.75	0 50	0 0033	375 99	0 50	0 0033	432.75	0 50	0 0033	432.75																	
1 80	0 50	0 0061	303 63	0 60	0 0032	340 93	0 60	0 0049	365 29	0 60	0 0049	395 22	0 50	0 0033	455.75	0 50	0 0033	395 22	0 50	0 0033	455.75	0 50	0 0033	455.75																	
2 10	0 50	0 0061	320 51	0 60	0 0032	351 11	0 60	0 0049	379 54	0 60	0 0049	414 45	0 50	0 0033	478.75	0 50	0 0033	414 45	0 50	0 0033	478.75	0 50	0 0033	478.75																	
2 40	0 60	0 0025	335 51	0 60	0 0032	361 29	0 60	0 0049	393 78	0 60	0 0049	433 68	0 50	0 0033	497.75	0 50	0 0033	433 68	0 50	0 0033	497.75	0 50	0 0033	497.75																	
2 70	0 60	0 0025	342 47	0 60	0 0032	371 47	0 60	0 0049	408 02	0 60	0 0049	451 42	0 50	0 0033	511.75	0 50	0 0033	451 42	0 50	0 0033	511.75	0 50	0 0033	511.75																	
3 00	0 60	0 0025	349 43	0 60	0 0032	381 65	0 60	0 0049	422 26	0 60	0 0049	464 36	0 50	0 0033	524.75	0 50	0 0033	464 36	0 50	0 0033	524.75	0 50	0 0033	524.75																	
3 30	0 60	0 0025	356 38	0 60	0 0032	391 83	0 60	0 0049	436 51	0 60	0 0049	478 70	0 50	0 0033	538.75	0 50	0 0033	478 70	0 50	0 0033	538.75	0 50	0 0033	538.75																	
3 60	0 60	0 0025	363 34	0 60	0 0032	402 01	0 60	0 0049	450 66	0 60	0 0049	492 61	0 50	0 0033	552.75	0 50	0 0033	492 61	0 50	0 0033	552.75	0 50	0 0033	552.75																	
3 90	0 60	0 0025	370 30	0 60	0 0032	412 20	0 60	0 0049	464 81	0 60	0 0049	506 86	0 50	0 0033	566.75	0 50	0 0033	506 86	0 50	0 0033	566.75	0 50	0 0033	566.75																	
4 20	0 60	0 0025	377 26	0 60	0 0032	422 38	0 60	0 0049	479 01	0 60	0 0049	521 01	0 50	0 0033	580.75	0 50	0 0033	521 01	0 50	0 0033	580.75	0 50	0 0033	580.75																	
4 50	0 60	0 0025	384 22	0 60	0 0032	432 56	0 60	0 0049	493 16	0 60	0 0049	535 16	0 50	0 0033	594.75	0 50	0 0033	535 16	0 50	0 0033	594.75	0 50	0 0033	594.75																	
4 80	0 60	0 0025	391 18	0 60	0 0032	442 74	0 60	0 0049	507 31	0 60	0 0049	549 31	0 50	0 0033	608.75	0 50	0 0033	549 31	0 50	0 0033	608.75	0 50	0 0033	608.75																	
5 10	0 60	0 0025	398 14	0 60	0 0032	452 92	0 60	0 0049	521 46	0 60	0 0049	563 46	0 50	0 0033	622.75	0 50	0 0033	563 46	0 50	0 0033	622.75	0 50	0 0033	622.75																	
5 40	0 60	0 0025	405 09	0 60	0 0032	463 10	0 60	0 0049	535 61	0 60	0 0049	577 61	0 50	0 0033	636.75	0 50	0 0033	577 61	0 50	0 0033	636.75	0 50	0 0033	636.75																	
5 70	0 60	0 0025	412 05	0 60	0 0032	473 28	0 60	0 0049	549 86	0 60	0 0049	593 86	0 50	0 0033	650.75	0 50	0 0033	593 86	0 50	0 0033	650.75	0 50	0 0033	650.75																	
6 00	0 60	0 0025	419 01	0 60	0 0032	483 46	0 60	0 0049	566 11	0 60	0 0049	608 11	0 50	0 0033	663.75	0 50	0 0033	608 11	0 50	0 0033	663.750																				

MATERIAL AS8.CEM.

YOM= 2000HRS																			

0 05 CUM/S				0 10 CUM/S				0 15 CUM/S				0 20 CUM/S				0 25 CUM/S			
E	PDM*	SHL	YTC	PDM*	SHL	YTC	FT	PDM*	SHL	YTC	FT	PDM*	SHL	YTC	FT	PDM*	SHL	YTC	FT
FT/KWH	M	M/M		M	M/M			M	M/M			M	M/M			M	M/M		
0 30	0 20	0.0144	44 02	0 25	0.0175	69.61		0 30	0.0153	99.06		0 40	0.0064	143 66		0 40	0.0097	155.67	
0 60	0 20	0.0144	51 56	0 25	0.0175	88 01		0 30	0.0153	123.14		0 40	0.0064	157 17		0 40	0.0097	181.18	
0 90	0 20	0.0049	58 87	0 30	0.0072	97 73		0 30	0.0153	147.23		0 40	0.0064	170.68		0 40	0.0097	206.70	
1 20	0 25	0.0049	61 42	0 30	0.0072	105 31		0 40	0.0038	153 95		0 40	0.0064	184 19		0 40	0.0097	232.21	
1 50	0 25	0.0049	63 97	0 30	0.0072	112 89		0 40	0.0038	159 90		0 40	0.0064	197 69		0 50	0.0035	245.49	
1 80	0 25	0.0049	66.52	0 30	0.0072	120 48		0 40	0.0038	165 85		0 40	0.0064	211 20		0 50	0.0035	254.11	
2 10	0 25	0.0049	69 07	0 30	0.0072	128 06		0 40	0.0038	171 80		0 40	0.0064	224 71		0 50	0.0035	262.74	
2 40	0 25	0.0049	71 63	0 30	0.0072	135 64		0 40	0.0038	177.75		0 40	0.0064	238 22		0 50	0.0035	271 36	
2 70	0 25	0.0049	74 18	0 30	0.0072	143 23		0 40	0.0038	183.70		0 50	0.0022	243 46		0 50	0.0035	279.99	
3 00	0 25	0.0049	76 73	0 40	0.0018	148 89		0 40	0.0038	189.65		0 50	0.0022	248 03		0 50	0.0035	288.62	
3 30	0 25	0.0049	79 28	0 40	0.0018	150 76		0 40	0.0038	195.60		0 50	0.0022	252 59		0 50	0.0035	297.24	
3 60	0 25	0.0049	81 83	0 40	0.0018	152 63		0 40	0.0038	201.55		0 50	0.0022	257 16		0 50	0.0035	305 87	
3 90	0 25	0.0049	84 38	0 40	0.0018	154 51		0 40	0.0038	207.50		0 50	0.0022	261 73		0 50	0.0035	314 50	
4 20	0 25	0.0049	86 93	0 40	0.0018	156 38		0 40	0.0038	213 45		0 50	0.0022	266 29		0 50	0.0035	323.12	
4 50	0 25	0.0049	89 49	0 40	0.0018	158 26		0 40	0.0038	219 40		0 50	0.0022	270 86		0 50	0.0035	331.75	
4 80	0 30	0.0020	91.80	0 40	0.0018	160 13		0 40	0.0038	225 35		0 50	0.0022	275 43		0 60	0.0014	336.74	
5 10	0 30	0.0020	92 86	0 40	0.0018	162 00		0 40	0.0038	231 30		0 50	0.0022	279 99		0 60	0.0014	340.30	
5 40	0 30	0.0020	93 91	0 40	0.0018	163 88		0 40	0.0038	237.25		0 50	0.0022	284 56		0 60	0.0014	345.85	
5 70	0 30	0.0020	94 96	0 40	0.0018	165 75		0 50	0.0013	240.58		0 50	0.0022	289 13		0 60	0.0014	347.41	
6 00	0 30	0.0020	96.01	0 40	0.0018	167 62		0 50	0.0013	242.59		0 50	0.0022	293 69		0 60	0.0014	350.97	

0 30 CUM/S				0 35 CUM/S				0 40 CUM/S				0 45 CUM/S				0 50 CUM/S			
0 30	0 50	0.0061	224 86	0 50	0.0078	235.28		0 50	0.0097	248.42		0 60	0.0049	305 48		0 60	0.0014	350.97	
0 60	0 50	0.0061	247 37	0 50	0.0078	268 21		0 50	0.0097	294 48		0 60	0.0049	331 12		0 60	0.0014	350.97	
0 90	0 50	0.0061	269 87	0 50	0.0078	301 14		0 60	0.0040	336 81		0 60	0.0049	356 76		0 60	0.0014	350.97	
1 20	0 50	0.0061	292.38	0 50	0.0078	334 07		0 60	0.0040	355 80		0 60	0.0049	382 40		0 60	0.0014	350 97	
1 50	0 50	0.0061	314 88	0 60	0.0032	347 71		0 60	0.0040	374 79		0 60	0.0049	408 04		0 60	0.0014	350 97	
1 80	0 60	0.0025	335.51	0 60	0.0032	361 29		0 60	0.0040	393 78		0 60	0.0049	433 68		0 60	0.0014	350 97	
2 10	0 60	0.0025	344.79	0 60	0.0032	374 86		0 60	0.0040	412.77		0 70	0.0023	454 45		0 60	0.0014	350.97	
2 40	0 60	0.0025	354 06	0 60	0.0032	388 44		0 60	0.0040	431.76		0 70	0.0023	466 57		0 60	0.0014	350.97	
2 70	0 60	0.0025	363 34	0 60	0.0032	402 01		0 70	0.0019	450 40		0 70	0.0023	478 70		0 60	0.0014	350 97	
3 00	0 60	0.0025	372 62	0 60	0.0032	415.59		0 70	0.0019	459.38		0 70	0.0023	490 82		0 60	0.0014	350.97	
3 30	0 60	0.0025	381 90	0 60	0.0032	429 16		0 70	0.0019	468 35		0 70	0.0023	502 94		0 60	0.0014	350 97	
3 60	0 60	0.0025	391.18	0 60	0.0032	442 74		0 70	0.0019	477 33		0 70	0.0023	515 06		0 60	0.0014	350.97	
3 90	0 60	0.0025	400 46	0 70	0.0015	453 05		0 70	0.0019	486 31		0 70	0.0023	527 18		0 60	0.0014	350.97	
4 20	0 60	0.0025	409 73	0 70	0.0015	459 45		0 70	0.0019	495 29		0 70	0.0023	539 31		0 60	0.0014	350.97	
4 50	0 60	0.0025	419.01	0 70	0.0015	465 86		0 70	0.0019	504.26		0 70	0.0023	551 43		0 60	0.0014	350 97	
4 80	0 60	0.0025	428 29	0 70	0.0015	472 28		0 70	0.0019	513.24		0 70	0.0023	563 55		0 60	0.0014	350 97	
5 10	0 60	0.0025	437 57	0 70	0.0015	478 70		0 70	0.0019	522.22		0 70	0.0023	575 67		0 60	0.0014	350 97	
5 40	0 60	0.0025	446 85	0 70	0.0015	485 12		0 70	0.0019	531 20		0 70	0.0023	587.79		0 60	0.0014	350.97	
5 70	0 70	0.0012	452 94	0 70	0.0015	491 54		0 70	0.0019	540 17		0 70	0.0023	599.91		0 60	0.0014	350.97	
6 00	0 70	0.0012	457 33	0 70	0.0015	497 95		0 70	0.0019	549.15		0 70	0.0023	612 04		0 60	0.0014	350 97	

MATERIAL **ASB.CEM.**

[illegible]

THE SPECIFIC HEADLOSS/SHL / BELONGING TO OPTIMUM VALUE OF /PDM*/
AND YEARLY TOTAL COST /YTC/

EN PRICE		0 05 CUM/S			0 10 CUM/S			0 15 CUM/S			0 20 CUM/S			0 25 CUM/S			MATERIAL		ASB.CEM.		YOH= 2500HRS	
E	FT/KWH	PDM*	SHL	YTC	PDM*	SHL	YTC	PDM*	SHL	YTC	PDM*	SHL	YTC	PDM*	SHL	YTC						
		M	M/M	FT	M	M/M	FT	M	M/M	FT	M	M/M	FT	M	M/M	FT						
0 30	0 0144	0 20	0 0144	45 90	0 25	0 0175	74 21	0 30	0 0153	105 08	0 40	0 0064	147 04	0 40	0 0097	162 05						
0 60	0 0164	0 20	0 0164	55 34	0 30	0 0072	93 93	0 50	0 0153	135 19	0 40	0 0064	163 92	0 40	0 0097	193 94						
0 90	0 0049	0 25	0 0049	60 78	0 30	0 0072	103 41	0 40	0 0038	152 47	0 40	0 0064	180 81	0 40	0 0097	225 83						
1 20	0 0250	0 25	0 0049	63 97	0 30	0 0072	112 89	0 40	0 0038	159 90	0 40	0 0064	197 69	0 50	0 0035	245 49						
1 50	0 0049	0 25	0 0049	67 16	0 30	0 0072	122 37	0 40	0 0038	167 34	0 40	0 0064	214 58	0 50	0 0033	256 27						
1 80	0 0049	0 25	0 0049	70 35	0 30	0 0072	131 85	0 40	0 0038	174 78	0 40	0 0064	231 47	0 50	0 0033	267 05						
2 10	0 0049	0 25	0 0049	73 54	0 30	0 0072	141 33	0 40	0 0038	182 22	0 40	0 0064	242 32	0 50	0 0033	278 83						
2 40	0 0049	0 25	0 0049	76 73	0 40	0 0018	148 89	0 40	0 0038	189 65	0 50	0 0022	248 03	0 50	0 0033	288 62						
2 70	0 0049	0 25	0 0049	79 92	0 40	0 0018	151 23	0 40	0 0038	197 09	0 50	0 0022	253 73	0 50	0 0033	299 40						
3 00	0 0049	0 25	0 0049	83 11	0 40	0 0018	153 57	0 40	0 0038	204 53	0 50	0 0022	259 44	0 50	0 0033	310 18						
3 30	0 0049	0 25	0 0049	86 30	0 40	0 0018	155 91	0 40	0 0038	211 97	0 50	0 0022	265 15	0 50	0 0033	320 91						
3 60	0 0049	0 25	0 0049	89 49	0 40	0 0018	158 26	0 40	0 0038	219 40	0 50	0 0022	270 86	0 50	0 0033	331 75						
3 90	0 0020	0 30	0 0020	92 07	0 40	0 0018	160 60	0 40	0 0038	226 84	0 50	0 0022	276 57	0 60	0 0014	337 63						
4 20	0 0020	0 30	0 0020	93 38	0 40	0 0018	162 94	0 40	0 0038	234 28	0 50	0 0022	282 28	0 60	0 0014	342 07						
4 50	0 0020	0 30	0 0020	94 70	0 40	0 0018	165 28	0 50	0 0013	240 07	0 50	0 0022	287 99	0 60	0 0014	346 52						
4 80	0 0020	0 30	0 0020	96 01	0 40	0 0018	167 62	0 50	0 0013	242 59	0 50	0 0022	293 69	0 60	0 0014	350 97						
5 10	0 0020	0 30	0 0020	97 33	0 40	0 0018	169 97	0 50	0 0013	245 10	0 50	0 0022	299 40	0 60	0 0014	355 41						
5 40	0 0020	0 30	0 0020	98 64	0 40	0 0018	172 31	0 50	0 0013	247 62	0 50	0 0022	305 11	0 60	0 0014	359 86						
5 70	0 0020	0 30	0 0020	99 96	0 40	0 0018	174 65	0 50	0 0013	250 13	0 50	0 0022	310 82	0 60	0 0014	364 30						
6 00	0 0020	0 30	0 0020	101 27	0 40	0 0018	176 99	0 50	0 0013	252 65	0 50	0 0022	316 53	0 60	0 0014	368 75						
0 30 CUM/S																						
0 30	0 0061	0 50	0 0061	230 49	0 50	0 0078	243 52	0 50	0 0097	259 93	0 60	0 0049	311 89	0 60	0 0014	368 75						
0 60	0 0061	0 50	0 0061	258 67	0 50	0 0078	284 67	0 50	0 0097	317 51	0 60	0 0049	343 94	0 60	0 0014	368 75						
0 90	0 0061	0 50	0 0061	286 75	0 50	0 0078	325 85	0 60	0 0040	351 05	0 60	0 0049	375 99	0 60	0 0014	368 75						
1 20	0 0061	0 50	0 0061	314 88	0 60	0 0032	347 71	0 60	0 0040	374 79	0 60	0 0049	408 04	0 60	0 0014	368 75						
1 50	0 0025	0 60	0 0025	337 83	0 60	0 0032	364 68	0 60	0 0040	398 53	0 60	0 0049	440 09	0 60	0 0014	368 75						
1 80	0 0025	0 60	0 0025	349 43	0 60	0 0032	381 65	0 60	0 0040	422 26	0 70	0 0023	460 51	0 60	0 0014	368 75						
2 10	0 0025	0 60	0 0025	361 02	0 60	0 0032	398 62	0 60	0 0040	446 00	0 70	0 0023	475 67	0 60	0 0014	368 75						
2 40	0 0025	0 60	0 0025	372 62	0 60	0 0032	415 59	0 70	0 0019	459 38	0 70	0 0023	490 82	0 60	0 0014	368 75						
2 70	0 0025	0 60	0 0025	384 22	0 60	0 0032	432 56	0 70	0 0019	470 60	0 70	0 0023	505 97	0 60	0 0014	368 75						
3 00	0 0025	0 60	0 0025	395 82	0 70	0 0015	447 84	0 70	0 0019	481 82	0 70	0 0023	521 12	0 60	0 0014	368 75						
3 30	0 0025	0 60	0 0025	407 41	0 70	0 0015	465 86	0 70	0 0019	493 04	0 70	0 0023	536 28	0 60	0 0014	368 75						
3 60	0 0025	0 60	0 0025	419 01	0 70	0 0015	483 88	0 70	0 0019	504 26	0 70	0 0023	551 45	0 60	0 0014	368 75						
3 90	0 0025	0 60	0 0025	430 61	0 70	0 0015	473 89	0 70	0 0019	515 49	0 70	0 0023	566 58	0 60	0 0014	368 75						
4 20	0 0025	0 60	0 0025	442 21	0 70	0 0015	481 91	0 70	0 0019	526 71	0 70	0 0023	581 73	0 60	0 0014	368 75						
4 50	0 0012	0 70	0 0012	451 84	0 70	0 0015	489 93	0 70	0 0019	537 93	0 70	0 0023	596 88	0 60	0 0014	368 75						
4 80	0 0012	0 70	0 0012	457 33	0 70	0 0015	497 95	0 70	0 0019	549 15	0 70	0 0023	612 04	0 60	0 0014	368 75						
5 10	0 0012	0 70	0 0012	462 81	0 70	0 0015	505 97	0 70	0 0019	560 37	0 70	0 0023	627 19	0 60	0 0014	368 75						
5 40	0 0012	0 70	0 0012	468 29	0 70	0 0015	514 00	0 70	0 0019	571 60	0 70	0 0023	642 34	0 60	0 0014	368 75						
5 70	0 0012	0 70	0 0012	473 77	0 70	0 0015	522 02	0 70	0 0019	582 82	0 70	0 0023	657 49	0 60	0 0014	368 75						
6 00	0 0012	0 70	0 0012	479 26	0 70	0 0015	530 04	0 70	0 0019	594 04	0 70	0 0023	672 65	0 60	0 0014	368 75						

THE OPTIMUM VALUE OF IRRIGATION PIPE DIAMETER /PDM*/
YEARLY ENERGY DEMAND /YED/ AND YEARLY ENERGY COST /YEC/

MATERIAL ASB.CEM.

EN PRICE		0 05 CUM/S			0 10 CUM/S			0 15 CUM/S			0 20 CUM/S			0 25 CUM/S			YOH= 2500HRS		
		0 05 CUM/S			0 10 CUM/S			0 15 CUM/S			0 20 CUM/S			0 25 CUM/S					
E	PDM*	YED	YEC	PDM*	YED	YEC	PDM*	YED	YEC	PDM*	YED	YEC	PDM*	YED	YEC	PDM*	YED	YEC	FT
FT/KWH	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	M	KWH	FT	
0 30	0 20	51 44	9 43	0 25	66 54	22 99	0 30	100 55	30 11	0 40	56 29	16 89	0 40	106 31	31 89				
0 60	0 20	31 44	18 87	0 30	51 50	18 96	0 30	100 55	30 21	0 40	56 29	33 77	0 40	106 31	63 79				
0 90	0 25	10 63	9 57	0 30	51 50	28 44	0 40	24 79	22 31	0 40	56 29	50 66	0 40	106 31	95 68				
1 20	0 25	10 63	12 76	0 30	51 50	37 92	0 40	24 79	29 75	0 40	56 29	67 54	0 50	35 94	43 13				
1 50	0 25	10 63	15 95	0 30	51 50	47 40	0 40	24 79	37 19	0 40	56 29	84 43	0 50	35 94	53 91				
1 80	0 25	10 63	19 13	0 30	51 50	56 88	0 40	24 79	44 63	0 40	56 29	101 31	0 50	35 94	64 70				
2 10	0 25	10 63	22 32	0 30	51 60	66 36	0 40	24 79	52 06	0 50	19 03	39 96	0 50	35 94	75 48				
2 40	0 25	10 63	25 51	0 40	7 81	18 74	0 40	24 79	59 50	0 50	19 03	45 67	0 50	35 94	86 26				
2 70	0 25	10 63	28 70	0 40	7 81	21 08	0 40	24 79	66 94	0 50	19 03	51 38	0 50	35 94	97 04				
3 00	0 25	10 63	31 89	0 40	7 81	23 42	0 40	24 79	74 38	0 50	19 03	57 09	0 50	35 94	107 83				
3 30	0 25	10 63	35 08	0 40	7 81	25 76	0 40	24 79	81 81	0 50	19 03	62 79	0 50	35 94	118 61				
3 60	0 25	10 63	38 27	0 40	7 81	28 10	0 40	24 79	89 25	0 50	19 03	68 50	0 50	35 94	129 39				
3 90	0 30	4 38	17 09	0 40	7 81	30 45	0 40	24 79	96 69	0 50	19 03	74 21	0 60	14 82	57 79				
4 20	0 30	4 38	18 41	0 40	7 81	32 79	0 40	24 79	104 13	0 50	19 03	79 92	0 60	14 82	62 23				
4 50	0 30	4 38	19 72	0 40	7 81	35 13	0 50	8 38	37 72	0 50	19 03	85 63	0 60	14 82	66 68				
4 80	0 30	4 38	21 04	0 40	7 81	37 47	0 50	8 38	40 23	0 50	19 03	91 34	0 60	14 82	71 13				
5 10	0 30	4 38	22 35	0 40	7 81	39 81	0 50	8 38	42 75	0 50	19 03	97 05	0 60	14 82	75 57				
5 40	0 30	4 38	23 67	0 40	7 81	42 16	0 50	8 38	45 26	0 50	19 03	102 76	0 60	14 82	80 02				
5 70	0 30	4 38	24 98	0 40	7 81	44 50	0 50	8 38	47 78	0 50	19 03	108 46	0 60	14 82	84 46				
6 00	0 30	4 38	26 30	0 40	7 81	46 84	0 50	8 38	50 29	0 50	19 03	114 17	0 60	14 82	88 91				
		0 30 CUM/S			0 35 CUM/S			0 40 CUM/S			0 45 CUM/S			0 50 CUM/S					
		0 30 CUM/S			0 35 CUM/S			0 40 CUM/S			0 45 CUM/S			0 50 CUM/S					
0 30	0 50	93 77	28 13	0 50	137 20	41 16	0 50	191 92	57 58	0 60	106 84	52 05	0 60	14 82	88 91				
0 60	0 50	93 77	56 26	0 50	137 20	82 32	0 50	191 92	115 15	0 60	106 84	64 10	0 60	14 82	88 91				
0 90	0 50	93 77	84 39	0 50	137 20	123 48	0 60	79 12	71 21	0 60	106 84	96 15	0 60	14 82	88 91				
1 20	0 50	93 77	112 53	0 60	56 56	67 87	0 60	79 12	94 95	0 60	106 84	128 20	0 60	14 82	88 91				
1 50	0 60	38 66	57 99	0 60	56 56	84 84	0 60	79 12	118 69	0 60	106 84	160 25	0 60	14 82	88 91				
1 80	0 60	38 66	69 59	0 60	56 56	101 81	0 60	79 12	142 42	0 70	50 51	90 91	0 60	14 82	88 91				
2 10	0 60	38 66	81 18	0 60	56 56	118 78	0 60	79 12	166 16	0 70	50 51	106 07	0 60	14 82	88 91				
2 40	0 60	38 66	92 78	0 60	56 56	135 75	0 70	37 41	89 78	0 70	50 51	121 22	0 60	14 82	88 91				
2 70	0 60	38 66	104 36	0 60	56 56	152 72	0 70	37 41	101 00	0 70	50 51	136 37	0 60	14 82	88 91				
3 00	0 60	38 66	115 98	0 60	56 56	169 69	0 70	37 41	112 22	0 70	50 51	151 52	0 60	14 82	88 91				
3 30	0 60	38 66	127 57	0 70	26 74	88 24	0 70	37 41	123 44	0 70	50 51	166 68	0 60	14 82	88 91				
3 60	0 60	38 66	139 17	0 70	26 74	96 76	0 70	37 41	134 66	0 70	50 51	181 83	0 60	14 82	88 91				
3 90	0 60	38 66	150 77	0 70	26 74	104 29	0 70	37 41	145 89	0 70	50 51	196 98	0 60	14 82	88 91				
4 20	0 60	38 66	162 37	0 70	26 74	112 31	0 70	37 41	157 11	0 70	50 51	212 13	0 60	14 82	88 91				
4 50	0 70	18 28	62 24	0 70	26 74	120 33	0 70	37 41	168 33	0 70	50 51	227 28	0 60	14 82	88 91				
4 80	0 70	18 28	87 73	0 70	26 74	128 35	0 70	37 41	179 55	0 70	50 51	242 44	0 60	14 82	88 91				
5 10	0 70	18 28	93 21	0 70	26 74	136 37	0 70	37 41	190 77	0 70	50 51	257 59	0 60	14 82	88 91				
5 40	0 70	18 28	98 69	0 70	26 74	144 40	0 70	37 41	202 00	0 70	50 51	272 74	0 60	14 82	88 91				
5 70	0 70	18 28	104 17	0 70	26 74	152 42	0 70	37 41	213 22	0 70	50 51	287 89	0 60	14 82	88 91				
6 00	0 70	18 28	109 66	0 70	26 74	160 44	0 70	37 41	224 44	0 70	50 51	303 05	0 60	14 82	88 91				

Input parameters for computer program of Model No.3

Diameters /PDM/ and specific cost of pipes /SPC/

Pipe material	Diameter PDM M	Specific cost SPC FT/M
Asbestos cement	0,080	420
	0,100	480
	0,125	590
	0,150	830
	0,200	1030
	0,250	1040
	0,300	1150
	0,400	1830
	0,500	2510
	0,600	3240
	0,700	3990

Pipe section, section lengths, and water discharge for critical path of each pumping unit variation

Variation	Section No.	MPL, SPL M	PWD CUM/S
A	P-1	1318	0,4860
	1-2	480	0,4050
	2-3	480	0,3240
	3-4	480	0,2430
	4-5	480	0,1620
	5-6	480	0,0810
	6-614	972	0,0405
	614-616	144	0,0270
	616-618	144	0,0135

Variation	Section No.	MPL,SPL M	PWD CUM/S
B	P-1	1318	0,3240
	1-2	480	0,2430
	2-3	480	0,1620
	3-4	480	0,0810
	4-414	972	0,0405
	414-416	144	0,0270
	416-418	144	0,0135
C	P-1	1318	0,2430
	1-2	480	0,1620
	2-3	480	0,0810
	3-314	972	0,0405
	314-316	144	0,0270
	316-318	144	0,0135
D	P-1	1318	0,1620
	1-2	480	0,0810
	2-214	972	0,0405
	214-216	144	0,0270
	216-218	144	0,0135
E	P-1	691	0,2430
	1-2	480	0,1620
	2-3	480	0,0810
	3-3 5	324	0,0405
	3 5-3 7	144	0,0270
	3 7-3 9	144	0,0135
F	P-1	691	0,1620
	1-2	480	0,0810
	2-2 5	324	0,0405
	2 5-2 7	144	0,0270
	2 7-2 9	144	0,0135

```

0      MASTER S3
1      REAL MSPL,NN,NX
2      LOGICAL THLOF
3      DIMENSION MUTPHL(9,2),MUTEED(9,2),PDM(10),MSPL(9),PWV(9),
4      *SIM(10),PHL(9,10),PWV(9,10),SHL(9,10),EED(9,10),S(9),XEED(9,10)
5      *XPHL(9,10)
6      COMMON PHI,MUTPHL,N,DB
7      DATA S/8H P-1 ,8H 1-2 ,8H 2-3 ,8H 3-4 ,
8      *      8H 4-5 ,8H 5-6 ,8H 6-614,8H 614-616,
9      *      8H 616-618/
10     READ(3,75) N,DB
11 75    FORMAT(I0,F0.0)
12     READ(1,11) (MSPL(K),K=1,N)
13 11    FORMAT(35F0.0)
14     READ(1,11) (PDM(K),K=1,N)
15     READ(1,17) PDM,SIM
16 17    FORMAT(10F0.0,/,10F0.0)
17     DO 100 ISZ=1,N
18     DO 101 IPDM=1,10
19     APWV=1.27*PWD(ISZ)/PDM(IPDM)**2
20     IF(APWV.LT.0.5.OR.APWV.GT.2.5) GO TO 102
21     PWV(ISZ,IPDM)=APWV
22     SHL(ISZ,IPDM)=0.21*0.7*(PWD(ISZ)**1.85)*(PDM(IPDM)**(-4.86))
23     PHL(ISZ,IPDM)=SHL(ISZ,IPDM)*MSPL(ISZ)*0.01
24     EED(ISZ,IPDM)=6482.6*PWD(ISZ)*PHL(ISZ,IPDM)
25     GOTO 101
26 102   PWV(ISZ,IPDM)=-1.
27 101   CONTINUE
28 100   CONTINUE
29 C
30 C      WRITE( 5,13, (((PWV(I,J),SHL(I,J),PHL(I,J)),J=1,10),I=1,9)
31 13    FORMAT(5X,3F10.5)
32 C
33 C
34     DO 200 ISZ=1,N
35     PMIN= 999999.
36     PMAX=-999999.
37     EMIN= 999999.
38     FMAX=-999999.
39     DO 201 IPDM=1,10
40     IF(PWV(ISZ,IPDM).EQ.-1.) GOTO 201
41     IF(PHL(ISZ,IPDM).LT.PMIN) GOTO 202
42 203   IF(PHL(ISZ,IPDM).GT.PMAX) GOTO 204
43 205   IF(EED(ISZ,IPDM).LT.EMIN) GOTO 206
44 207   IF(EED(ISZ,IPDM).GT.EMAX) GOTO 208
45     GOTO 201
46 202   PMIN=PHL(ISZ,IPDM)
47     MUTPHL(ISZ,1)=IPDM
48     GOTO 203
49 204   PMAX=PHL(ISZ,IPDM)
50     MUTPHL(ISZ,2)=IPDM
51     GOTO 205
52 206   FMIN=EED(ISZ,IPDM)
53     MUTEED(ISZ,1)=IPDM
54     GOTO 207
55 208   EMAX=EED(ISZ,IPDM)
56     MUTEED(ISZ,2)=IPDM
57 201   CONTINUE
58 200   CONTINUE

```

```

60 14      FORMAT(10X,2I17)
61      IF(THL0K(SS)) GOTO 1000
62 400     DO 300 ISZ1=1,N
63         ISZ=10-ISZ1
64         MUTPHL(ISZ,2)=MUTPHL(ISZ,2)-1
65         IF( MUTPHL(ISZ,2).LT.MUTPHL(ISZ,1))
66 *         MUTPHL(ISZ,2)=MUTPHL(ISZ,1)
67         IF(MUTEED(ISZ,1).NE.MUTPHL(ISZ,2))
68 *         MUTEED(ISZ,1)=MUTPHL(ISZ,2)
69         IF(THL0K(SS)) GOTO 1000
70 300     CONTINUE
71         GOTO 400
72 1000    CALL F1
73 6       WRITE(5,18) (((MUTPHL(I,K)),K=1,2),I=1,9)
74 18      FORMAT(10X,2I17)
75         DO 500 ISZ=1,N
76             DO 7 K=1,10
77                 XPHL( ISZ,K)=4H
78 7         XEED( ISZ,K)=4H
79             I1=MUTPHL( ISZ,1)
80             I2=MUTPHL(ISZ,2)
81             K1=MUTEED( ISZ,1)
82             K2=MUTEED( ISZ,2)
83             XFED(ISZ,I1)=4HMIN
84             XEED( ISZ,I2)=4HMAX
85             XPHL( ISZ,I1)=4HMIN
86             XPHL( ISZ,I2)=4HMAX
87             I=ISZ
88         WRITE(5,501) S(I),MSPL(I),PWD(I)
89 501     FORMAT(1X,A8,F7.0,F8.4)
90         DO 505 J=1,10
91             IF(P1V(ISZ,J).EQ.-1.) GOTO 505
92             WRITE(5,506) PD1(J),PWV(ISZ,J),SHL(ISZ,J),PHL(ISZ,J),
93 *FED(ISZ,J),XPHL(ISZ,J),XEED(ISZ,J)
94 506     FORMAT(25X,F8.3,F7.2,F8.2,F8.2,F9.2,4X,
95 *A4,5X,A4)
96 505     CONTINUE
97 500     CONTINUE
98         THL=0.0
99         DO 3 ISZ=1,N
100        IND=MUTPHL(ISZ,1)
101 3       THL=THL+PHL(ISZ,IND)
102 4       CONTINUE
103        WRITE( 5,12) THL
104 12      FORMAT(/,5X,4HTHL=,F10.4)
105        R=1.
106        NM=0.
107        NX=0.
108        DO 314 ISZ=1,N
109            IN=MUTPHL(ISZ,1)
110            IX=MUTPHL(ISZ,2)
111            IF( ISZ.GT.1-3) R=DR
112            NI=NM+R*MSPL(ISZ)*SIM(JX)
113            NX=NX+R*MSPL(ISZ)*SIM(IX)
114 314     CONTINUE
115        WRITE(5,315) NM,NX
116 315     FORMAT( //,50X,7HNI=,F15.2,/,50X,7HNI=,F15.2)
117        STOP
118        END

```

```

120      WRITE(5,10)
121 10    FORMAT(1H1,/,/,3X,26HTECHNICAL CHARACTERISTICS ,
122      *20HOF IRRIGATION PLANTS)
123      WRITE(5,20)
124 20    FORMAT(/,86X,1XHMATERIAL: ASB.CEM.,/,4X,13HA - VARIATION,/,
125      *86X,9HPFF = 0.7,/,86X,9HAHL = 30M)
126      V=1H-
127      WRITE(5,30) (V,K=1,110)
128 30    FORMAT(1X,110A1)
129      WRITE(5,40)
130 40    FORMAT(2X,7HSECTION,1X,10H MPL,SPL ,10H PWD      P,
131      *5HDM      ,2X,3HPWL,5X,3HSHL,6X,3HPhL,4X,3HEED,6X,3HPhL,
132      *6X,3HEED,/,5X,2HNO,61X,7HMIN/MAX,2X,7HMIN/MAX)
133      WRITE(5,50)
134 50    FORMAT(14X,1HM,5X,5HCUM/S,5X,1HM,6X,3HM/S,5X,6HM/100M,
135      *6X,1HM,5X,3HKWH,7X,1HM,7X,3HKWH)
136      WRITE(5,30)(V,K=1,110)
137      RETURN
138      END
139      LOGICAL FUNCTION THLOK( S)
140      DIMENSION PHL(9,10),MUTPHL(9,2)
141      COMMON PHL,MUTPHL,N,DB
142      THL=0.
143      S=S
144      DO 300 ISZ=1,N
145      IND=MUTPHL(ISZ,2)
146 300    THL=THL+PHL(ISZ,IND)
147 4    CONTINUE
148      IF(THL.LT.30.) GOTO 59
149      THLOK=.FALSE.
150      RETURN
151 59    THLOK=.TRUE.
152      RETURN
153      END
154      C
155      C
156      C
157      FINISH
158      FILLER

```

Results of computer programming for Model No.3

TECHNICAL CHARACTERISTICS OF IRRIGATION PLANTS

A - VARIATION										MATERIAL		ASU CEM	
										PFF = 0.7		AHL = 30M	
SECTION NO	MPL,SPL	PWD	PDH	P4V	SHL	PHL	EED	PHL	EED	MIN/MAX	MIN/MAX	MIN	MAX
										M		KWH	
										M/100M		M	
										M/S		KWH	
										M		KWH	
										M		KWH	
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TECHNICAL CHARACTERISTICS OF IRRIGATION PLANTS

MATERIAL ASB CEM.

PFF = 0.7
AHL = 30M

B - VARIATION

SECTION NO	MPL/SPL	PUD	PDM	P4V	SHL	PHL	EED	PHL	EED	PHL	EED
		CUM/S	M	M/S	M/100M	M	KWH	M	KWH	M	KWH
P-1	(1380)	0.3240	0.700	0.84	0.10	1.43	2997.94	MIN	MIN	MIN	MIN
			0.600	1.14	0.22	3.02	6341.38	MAX	MAX	MAX	MAX
			0.500	1.65	0.53	7.52	15381.71				
1-2	480	0.2430	0.700	0.63	0.06	0.29	459.31	MIN	MIN	MIN	MIN
			0.600	0.86	0.13	0.62	971.56				
			0.500	1.23	0.31	1.50	2356.65	MAX	MAX	MAX	MAX
			0.400	1.93	0.92	4.43	6970.66				
2-5	480.	0.1620	0.600	0.57	0.06	0.29	305.92	MIN	MIN	MIN	MIN
			0.500	0.82	0.15	0.71	742.05				
			0.400	1.29	0.44	2.09	2194.90	MAX	MAX	MAX	MAX
			0.300	2.29	1.76	8.46	8884.16				
3-4	480	0.0810	0.400	0.54	0.12	0.58	304.42	MIN	MIN	MIN	MIN
			0.300	1.14	0.49	2.35	1232.20	MAX	MAX	MAX	MAX
			0.250	1.55	1.19	5.69	2988.83				
4-414	(970)	0.0405	0.300	0.57	0.14	1.32	345.36	MIN	MIN	MIN	MIN
			0.250	0.82	0.33	3.19	837.72	MAX	MAX	MAX	MAX
			0.200	1.29	0.97	9.44	2477.87				
			0.150	2.29	3.94	38.20	10029.55				
414-416	144	0.0270	0.250	0.55	0.16	0.27	59.16	MIN	MIN	MIN	MIN
			0.200	0.86	0.46	0.66	115.83	MAX	MAX	MAX	MAX
			0.150	1.52	1.86	2.68	468.83				
			0.125	2.19	4.51	6.50	1137.19				
416-418	144.	0.0135	0.150	0.76	0.52	0.74	65.02	MAX	MAX	MAX	MAX
			0.125	1.10	1.25	1.80	157.72				
			0.100	1.71	3.70	5.53	466.53				

THL= 29.0445

NICMIN= 15677720.00
NICMAX= 20933240.00

Appendix 4.10

TECHNICAL CHARACTERISTICS OF IRRIGATION PLANTS

C - VARIATION										MATERIAL ASB CEM.	
										PFF = 0.7	
										AHL = 30M	
SECTION NO	MPL,SPL	PWD	PDM	P4V	SHL	PHL	EED	PHL MIN/MAX	EED MIN/MAX		

Appendix 4.10

TECHNICAL CHARACTERISTICS OF IRRIGATION PLANTS

MATERIAL ASD CEM

PFF = 0.7
AHL = 50M

E - VARIATION

SECTION NO	MPL,SPL	PUD	CUM/S	PDM	PAV	SHL	PHL		EFD	PHL		FED
							M	M/100M		M	KWH	
-1 CUM/S												
MIN/MAX												
KWH												
P-1	691	0 2430		0 700	0 63	0 06	0 42	601 22		MIN		MIN
				0 600	0 86	0 15	0 89	1598 64				
				0 500	1 23	0 51	2 15	3392 57				
				0 400	1 93	0 92	6 37	10034 85		MAX		MAX
1-2	480	0 1620		0 600	0 57	0 06	0 29	305 92		MIN		MIN
				0 500	0 82	0 15	0 71	742 05				
				0 400	1 29	0 44	2 09	2194 90				
				0 300	2 29	1 76	8 46	8884 16		MAX		MAX
2-3	480	0 0810		0 400	0 64	0 12	0 58	304 42		MIN		MIN
				0 300	1 14	0 49	2 35	1232 20				
				0 250	1 55	1 19	5.09	2988 83		MAX		MAX
3-314	324.	0 0405		0 300	0 57	0 14	0 44	115 36		MIN		MIN
				0 250	0 82	0 35	1 07	279 81				
				0 200	1 29	0 97	3 15	827 66		MAX		MAX
				0 150	2 29	3 94	12 76	3350 08				
314-316	144.	0 0270		0 250	0 55	0 16	0 22	39 16		MIN		MIN
				0 200	0 86	0 46	0 66	115 83				
				0 150	1 52	1 86	2 68	468 83		MAX		MAX
				0 125	2 19	4 51	6 50	1137 19				
316-318	144	0 0135		0 150	0 76	0 52	0 74	65 02		MIN		MIN
				0 125	1 10	1 25	1 80	157 72		MAX		MAX
				0 100	1 71	3 70	5 53	466 53				

THL= 28 1532

NICMIN= 5544930 00
NICMAX= 9041970 00

TECHNICAL CHARACTERISTICS OF IRRIGATION PLANTS

MATERIAL ASB CEM

PFF = 0.7
AHL = 30M

F - VARIATION

SECTION NO	MPL,SPL	PWD	PDM	PAV	SHL	PHL		EED	
						M	KUH	MIN/MAX	MIN/MAX
Y	CU1/S	M	M/S	M/100M	M	KUH	M	KUH	
P-1	691	0 1620	0 600	0 57	0 06	0 42	440 40	MIN	MIN
			0 500	0 82	0 15	1 02	1068 24		
			0 400	1 29	0 44	3 01	5159 74		
			0 300	2 29	1 76	12 18	12789 49	MAX	MAX
1-2	480	0 0810	0 400	0 54	0 12	0 58	304 42	MIN	MIN
			0 300	1 14	0 49	2 35	1232 20		
			0 250	1 65	1 19	5 69	2988 83	MAX	MAX
2-214	524	0 0405	0 500	0 57	0 14	0 44	115 36	MIN	MIN
			0 250	0 82	0 33	1 07	279 81		
			0 200	1 29	0 97	3 15	827 66	MAX	MAX
			0 150	2 29	3 94	12 76	3350 08		
214-216	144	0 0270	0 250	0 55	0 16	0 22	59 16	MIN	MIN
			0 200	0 86	0 46	0 66	115 83		
			0 150	1 52	1 86	2 68	468 83	MAX	MAX
			0 125	2 19	4 51	6 50	1157 19		
216-218	144	0 0135	0 150	0 76	0 52	0 74	65 02	MIN	MIN
			0 125	1 10	1 25	1 80	157 72	MAX	MAX
			0 100	1 71	3 70	5 33	466 53		

THL= 25 5036

NICHIN= 544650 00
NICMAX= 5684760 00

The overall characteristics of examined model plants for 3000 HA
irrigated land

Appendix 4.11

Vari- ation	No. of pump stations	Length of canal M	Water disch. TWD CUM/S	El.power EPD KW	Trans- former KVA	Investment		costs, MFT		Pipe-line		Total, MFT	
						Pumps	En suppl.	Water		MIN	MAX	MIN	MAX
A	1,0	2880	2,100	3570	5000	PIC	EIC	WIC		MIN	MAX	MIN	MAX
B	1,5	3840	1,400	2380	3200	25,2	4,1	7,2		97,4	121,7	133,9	158,2
C	2,0	4320	1,100	1870	2500	29,4	4,6	9,6		94,1	125,6	127,7	159,2
D	3,0	4800	0,700	1190	1600	35,2	5,4	10,8		94,3	128,4	145,7	179,8
E	4,0	8640	0,550	935	1250	37,8	5,9	12,0		93,4	128,4	149,1	184,1
F	6,0	9600	0,350	595	1000	44,0	8,9	21,6		91,0	131,0	165,5	205,5
						46,2	9,3	24,0		89,0	135,0	168,5	214,5

Energy demand and energy cost for examined model plants
for 3000 HA of irrigated land

Appendix 4.12

Vari- ation	Energy Demand, KWH/HA			Energy cost, FT/HA ^x			Energy cost, FT/HA ^{xx}							
	MIN	1200	3000	MAX	1200	3000	MIN	600	3000	MAX				
A	225,0	450,0	1125,0	291,6	583,2	1458,0	225	1125	292	1458	675	3375	875	4374
B	215,3	430,6	1076,5	299,7	599,4	1498,5	215	1076	299	1998	646	3229	899	4498
C	212,3	424,4	1061,0	289,8	579,6	1449,0	212	1061	290	1449	637	3183	869	4347
D	211,8	423,6	1059,0	296,5	593,0	1482,5	212	1059	296	1482	635	3177	889	4447
E	210,7	421,7	1054,0	292,5	585,0	1462,5	211	1054	292	1462	632	3162	877	4287
F	209,2	418,4	1046,0	295,5	591,0	1477,5	209	1046	295	1477	628	3138	886	4432

^x E = 1,0 FT/KWH

^{xx} E = 3,0 FT/KWH

Fixed operation costs of examined model plants
for 3000 HA of irrigated land

Appendix 4.13

Vari- ation	Fixed costs, MFT/YEAR				Specific fixed costs										
	Mach- ines	Establisshm.		Main- tenance	Total		MIN		MAX		MIN		MAX		FT/CUM
		MIN	MAX		MIN	MAX	FT/HA	FT/HA	600	1200	3000	600	1200	3000	
A	3,33	12,17	14,90	2,52	18,03	18,75	6010	6250	10,0	5,0	2,0	10,4	5,2	2,1	2,1
B	3,88	11,01	14,54	2,94	17,83	21,36	5943	7150	9,9	4,5	1,9	11,9	5,9	2,4	2,4
C	4,65	12,39	16,21	3,52	20,56	24,38	6853	8277	11,4	5,7	2,3	13,8	6,9	2,7	2,7
D	4,99	12,47	16,49	3,78	21,24	25,26	7080	8420	11,8	5,9	2,3	14,0	7,0	2,8	2,8
E	5,01	13,61	18,09	4,40	23,82	28,30	7940	9433	13,2	6,6	2,6	15,7	7,8	3,1	3,1
F	6,10	13,70	18,55	4,62	24,42	29,57	8140	9857	13,6	6,8	2,7	16,4	8,2	3,3	3,3

Yearly total operation costs of examined
model plants for 3000 HA of irrigated land

Appendix 4.14

E = 3,0 FT/KWH

Vari- ation	600 CUM/HA						1200 CUM/HA						3000 CUM/HA					
	MIN		MIN		MIN		MIN		MIN		MIN		MIN		MIN		MIN	
	INV	FT/HA	INV	FT/HA	INV	FT/HA	INV	FT/HA	INV	FT/HA	INV	FT/HA	INV	FT/HA	INV	FT/HA	INV	FT/HA
A	6885	6925	11,5	11,5	7760	7600	6,5	6,3	10384	9625	3,5	3,2	10384	9625	3,5	3,2	10384	9625
B	6842	7766	11,4	12,9	7741	8412	6,4	7,0	10438	10349	3,5	3,4	10438	10349	3,5	3,4	10438	10349
C	7722	8914	12,9	14,8	8592	9550	7,1	7,9	11200	11450	3,7	3,8	11200	11450	3,7	3,8	11200	11450
D	7969	9055	13,3	15,1	8859	9691	7,4	8,1	11527	11597	3,8	3,8	11527	11597	3,8	3,8	11527	11597
E	8817	10065	14,7	16,8	9655	10689	8,0	8,9	12327	11592	4,1	4,2	12327	11592	4,1	4,2	12327	11592
F	9026	10484	15,0	17,5	9913	11112	8,3	9,3	12572	12995	4,2	4,3	12572	12995	4,2	4,3	12572	12995

Yearly total operation costs of examined
model plants for 3000 HA of irrigated land

Appendix 4.15

E = 6,0 FT/KWH

Vari- ation	600 CUM/HA						1200 CUM/HA						3000 CUM/HA					
	MIN		MIN		MIN		MIN		MIN		MIN		MIN		MIN		MIN	
	INV	EN	INV	EN	INV	EN	INV	EN	INV	EN	INV	EN	INV	EN	INV	EN	INV	EN
	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA	FT/HA
A	7760	7600	12,9	12,6	12,6	12,6	9510	8950	7,9	7,5	14758	13000	4,9	4,3				
B	7741	8412	12,9	14,0	14,0	14,0	9539	9504	7,9	7,9	14933	13578	5,0	4,5				
C	8591	9551	14,3	15,9	15,9	15,9	10331	10823	8,6	8,4	15547	14643	5,2	4,9				
D	8858	9690	14,8	16,1	16,1	16,1	10638	10962	8,9	8,5	15974	14774	5,3	5,0				
E	9694	10697	16,1	17,8	17,8	17,8	11450	11960	9,5	10,0	16714	15757	5,6	5,2				
F	9912	11111	16,5	18,5	18,5	18,5	11686	12367	9,7	10,3	17004	16133	5,7	5,4				