IJST, Transactions of Civil Engineering, Vol. 38, No. C1+, pp 297-307
Printed in The Islamic Republic of Iran, 2014

DEVELOPMENT OF MICRO IRRIGATION DESIGN SOFTWARE (MIDS) TO OPTIMIZE TOTAL PROJECT COST AND HYDRAULIC PARAMETERS*

A. A. GHAEMI** AND A. TABARZAD

Dept. of Water Engineering, College of Agriculture, Shiraz University, Shiraz, I. R. of Iran
Email: ghaemi@shirazu.ac.ir

Abstract– Iran is a large producer of agricultural products. Irrigation water resources are limited and the water use efficiency is low. The micro irrigation system (MIS) is a versatile management tool that can increase water productivity. Although micro irrigation has a lot of advantages, some of its disadvantages are its difficult and time-consuming design. Economical analysis of the design is one of the main factors that should be considered. This study introduces a model developed in Visual Basic called Micro Irrigation Design Software (MIDS). The software can design a MIS for various crops, climate, and topographic conditions. It calculates the primary design parameters such as ET_o, ET_C, irrigation water depth, wetting pattern and leaching fraction. This software determines suitable arrangements of pipes, pipe length and diameter, emitters, hydraulic parameters design, and head loss. The manifolds and main pipes could be designed as mono-diameter and telescopic, and the optimized size is reported to the user. The focus of this software is on economic analysis in accordance with electricity price, energy consumption use and initial and operation projects costs. To examine the software accuracy, some executed projects (manually designed) in Fars province were rechecked considering electricity energy price in Iran. Results showed that the Software was able to provide more reliable design parameters, also with electricity price build-up to more than a certain limit, It would be possible to increase the pipeline diameters to a certain extent with a better economic result during the project lifetime.

Keywords– Micro irrigation design, software, hydraulic parameters, economic analysis

1. INTRODUCTION

Today, the water crisis is one of the most important problems worldwide. Since water is essential in the production of food and energy, it plays a key role in a country's political, social, and economical independence. These factors are even more significant for countries located in the arid and semi arid belt of the world. Due to limited water sources, growing population and consecutively drought conditions in these countries, it is crucial to preserve water sources and to economize and optimize water utilization. Since the biggest consumer of water is the agricultural section with about 85-90% of water usage, it is necessary to optimize water supply [1]. Applying modern irrigation systems such as the pressurized irrigation system (micro or sprinkler) has high water-use efficiency and is a beneficial irrigation method. Micro irrigation system has become popular in Iran and it has adapted to more than 400000 ha and is estimated to increase by 100% (800,000 ha) during the next 5 years [1]. However, there are some defects in pressurized irrigation systems including high primary cost, installation and performance, maintenance, reparation and complexity in design. Fortunately the micro irrigation system has been adopted by most farmers because of its practicality, high application efficiency, lack of need for field

*Received by the editors February 22, 2013; Accepted July 9, 2013.
**Corresponding author

smoothing, feasibility in mountains, hillsides, and hills, ability to be injected with fertilizers and chemicals, ease of installation, good performance, and ability to produce all its devices and fittings in most countries [2-4].

One of the biggest problems with this system, however, is its design complexity and it is time consuming. There are many hydraulics parameters and factors involved in its design which, if ignored, would jeopardize its efficiency and diminish its emission uniformity coefficient. On the other hand, it is a known fact that computer programs are successfully used in a variety of sciences and situations to solve various complex equations and design hydraulic parameters. Among the many advantages of computer technology is that it not only reduces the time required for the iteration of long functions and calculations but that it also increases accuracy. Therefore, considering the wide application of technology in society and its positive contributions to human life, it is suggested that a computer model be developed to design irrigation systems such as the micro irrigation for application in the fields. Molina-Martineza et al. [5] introduced a software package program to determine the lateral diameter with its in-line emitter numbers with respect to the type of crop, crop water requirement, and plant spacing. This program can be installed on cell phone, pocket computer, or any portable electronic (computer) device. Cook et al. [6] produced software called (Wet Up) to predict soil wetted area for each emitter.

Meshkat and Warner [7] developed a user friendly model In order to design micro irrigation system and calculate hydraulic parameters at 3 different parts such as: 1- water conveyance, selection type of crop and emitter design, 2- subunit hydraulics design, 3- main pipe network design. Allen et al. [8] produced SPRINKMOD program for Windows. This model can simulate the nozzle pressure and discharge in sprinkler irrigation systems.

Unfortunately, in Iran there is no codified, reliable, and extensive, multilingual (such as English and Farsi) software available to lead technicians and micro irrigation experts in designing these systems. Therefore, it is essential to present a computer model with the ability to design a micro irrigation system with various hydraulic, economic, and technological aspects. The Micro Irrigation Design Software (MIDS) introduced in this paper is able to design a micro irrigation system in various topography, climate and environmental conditions and optimized total project cost of MIS.

The objectives of this study are I- to develop and introduce a software program in which the designer can design the micro irrigation system in different land topographic, climate, and crop type conditions, II- to determine and optimize the hydraulic parameters in micro irrigation system, and III- to optimize total project cost including the impact of cost of electricity in micro irrigation system design.

2. MATERIAL AND METHODS

Research theoretical concepts

The Visual Basic Programming Language was used to write the MIDS model. This language has great power in Windows, and has several advantages such as simplicity in developing or producing a program, being user friendly, and ability to apply different languages such as English, Farsi, and etc. to the program [9]. These characters and many other benefits from Visual Basic Programming Language make it suitable for writing the computational model called "MIDS" model in this research. Therefore, the model was written in both English and Farsi Languages and all pages and frames which are exposed to the user are in both Languages. It is noticeable that the graphical characteristics of the Visual Basic lead to making an easy and quick connection with the user. There are many equations, pathways and terms which have been used in this model and some of these terms are introduced as follows.

The reference evapotranspiration (ET_o) was calculated by FAO, Penman-FAO, FAO-Penman Monteith, Hargreaves-Samani, Blaney-Criddle, and Pan evaporation methods. Moreover, the user can directly insert reference crop evapotranspiration or type of crop into the model. The reference crop evapotranspiration can be estimated by FAO-Penman-Montieth equation as follows [10, 2, 4]:

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma\left[900/\left(T+273\right)\right]U_2\left(e_a - e_d\right)}{\Delta + \gamma\left(1+0.34u_2\right)} \tag{1}$$

Where, ET_o: reference evapotranspiration ($mmday^{-1}$), R_n: net radiation at the crop surface ($MJm^{-2}d^{-1}$), T: air temperature at 2 meters height (°C), U_2: wind speed at 2 meters height (ms^{-1}), ea-ed: saturation vapor pressure deficit at 2 meters above ground surface (kPa), Δ: slope vapor pressure curve (kPa°C^{-1}), G: soil heat flux density ($MJm^{-2}day^{-1}$), and γ: psychometric constant (kPa°C^{-1}). The reference evapotranspiration, ET_o, provides a standard value at various time periods within a year in different regions, and finally crop evapotranspiration can be calculated.

In all different equations it is necessary to calculate crop coefficient (K_c). The MIDS model calculates K_c in two ways: a single crop coefficient method and a dual crop coefficient method.

Then the crop evapotranspiration is calculated by equation 2 [10]:

$$ET_c = ET_o \times K_c \tag{2}$$

In general, crop water requirement is the summation of evaporation from the soil surface and the transpiration from the crop. In micro irrigation, soil surface evaporation is reduced to the lowest amount but transpiration constitutes nearly all the water consumption. In order to calculate the crop water requirement in a micro irrigation system, it is not necessary to soak the entire farm when irrigating the crop as is done in some other irrigation systems. The crop water requirement calculation in a micro irrigation system must, therefore, be modified.

Plant transpiration can be determined by FAO, corrected FAO, SCS and Keller and Bleisner methods. Equation (3) has been suggested by Keller and Bliesner [11] to estimate the plant transpiration:

$$T_d = U_d\,[0.1(P_d)^{0.5}] \tag{3}$$

Where, T_d is average daily transpiration rate during the peak-use month for a crop under micro irrigation (mm/day), U_d: conventionally estimated average daily consumptive use rate during the use-peak month for the mature crop with a full canopy (mm/day), P_d the percentage of soil surface area shaded by crop canopies at midday (solar noon).

The leaching fraction is also determined by MIDS model using two different equations which can be selected by user, one of them is equation 4 [12]. The leaching fraction is the amount of extra irrigation water that must be applied above the amount required by the crop in order to maintain acceptable root zone salinity [13]:

$$LF = \frac{EC_w}{5EC_e - EC_w)} \tag{4}$$

Where: ECe is the maximum electrical conductivity of soil saturated extract (ds/m) in which the plant has been eliminated, ECw is the electrical conductivity of irrigation water(ds/m).

Percentage of soil wetted area along a horizontal plane, generally measured 15-30 cm depth below soil surface in micro irrigation system under each emitter is considered. The model also determines the soil wetted depth and maximum wetted diameter. Several factors such as emitter discharge, irrigation duration, soil texture, and structure impact on the wetted area. In this model, the depth and wetted diameter of soil can be estimated by 5 and 6 [14]:

$$Z = 29.2(V_w)^{0.63}\left(\frac{ks}{q}\right)^{0.45} \quad (5)$$

$$W = 0.031(V_w)^{0.22}\left(\frac{ks}{q}\right)^{-0.17} \quad (6)$$

Where, Z is soil wetted depth below each emitter (m), q: emitter discharge (L/h), V_W is Volume of water delivered from each emitter (L), ks is soil saturated conductivity (m/s), and W is maximum wetted diameter of soil wetted pattern (m).

To consider the hydraulic design of pipes by model, first of all, several hydraulic parameters such as Christiansen uniformity coefficient, emitter discharge and pressure variations and head loss are determined. Christiansen uniformity coefficient is computed by equation 7 [15] as follows.

$$UC = 1 - \frac{\Delta\bar{q}}{\bar{q}} \quad (7)$$

Where, *UC is* Christiansen uniformity coefficient, Δq is average absolute deviation of all emitters' discharge from the average emitter discharge and *qbar*, the mean emitter discharge rate.

The other method for investigating the emitter discharge variations is to compare the maximum and minimum discharge in emitters [12, 16]:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \quad (8)$$

Where, q_{var} is emitter discharge variation, q_{max} is maximum emitter discharge, and q_{min} is minimum emitter discharge.

The pressure variation and relationship between emitter discharge variation and pressure variations are shown in equations 9 and 10

$$q_{var} = 1 - (1 - H_{var})^x \quad (9)$$

$$H_{var} = \frac{H_{max} - H_{min}}{H_{max}} \quad (10)$$

Where, H_{var} is pressure variation, H_{max} the maximum pressure in line, and H_{min} is minimum pressure. Hazen-Williams equation was used to determine the pressure loss based on friction [11, 17]:

$$h_f = K.L\frac{(\frac{Q}{C})^{1.852}}{D^{4.87}} \quad (11)$$

Where, h_f is friction head loss (L), K refers to a constant coefficient, dependent on the variable units, L is pipe length (L), Q is discharge (L^3/T), C is Hazen-Williams friction coefficient which varies in different pipes, and D is pipe diameter (L). In addition, the MIDS model is also able to determine Langelier Saturation Index (LSI) and all parameters necessary for flushing the pipelines and emitters with different acids and chlorine. LSI is an equilibrium model derived from the theoretical concept of saturation and provides an indicator of the degree of saturation of water with respect to calcium carbonate [18]. Moreover, the MIDS model also calculates essential parameters to avoid biological clogging in emitters by chlorination. An economic analysis of the pipelines is also done by the model using the present value method. The many other functions and methods used by the model are not mentioned here.

3. MODEL DEVELOPMENT

As mentioned before, this software is written based on the Visual Basic Language. Visual basic language is an objective programming Language. To perform the model, the user will be exposed to different pages, each with a special duty to execute a special part of the program. Micro irrigation system design (MIDS) has been written in 14000 lines and more than 100 pages. After running the model a primary main frame is shown. The user can choose from different options to reach different parts of the (MIDS).

The MIDS model has been developed in such a way that user could execute the model step by step as explained and shown in the windows tool box, or choose their own steps. The user is even able to use just a specific section of the model without being limited to continue the micro irrigation design computation.

Model provides the pipe hydraulic design based on the information such as outside diameter, inside diameter, length unit, weight of pipes on PE_{63} and PE_{80} standards, and many other hydraulic parameters. Moreover, the user is able to add the additional pipe diameters except the ones that have been established in the software memory (Fig. 1 shows the page that includes these characteristics in the model).

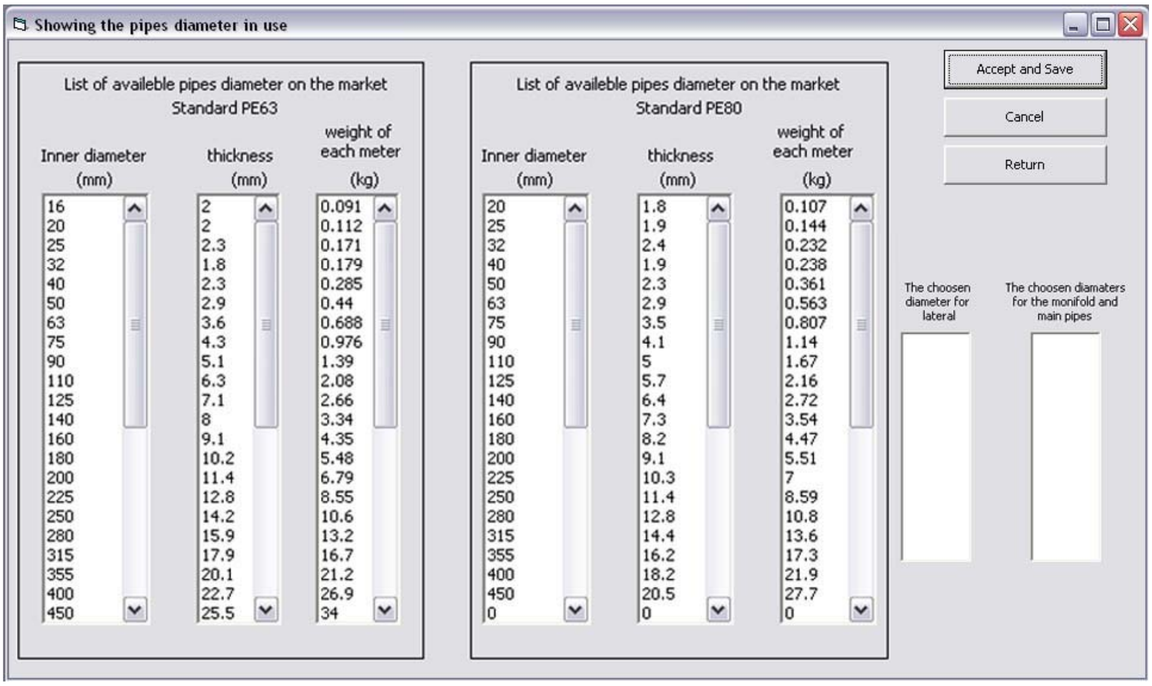

Fig. 1. The polyethylene pipes characteristics for PE63 and PE80 standards

The software could also design the user's interested system arrangement in two different field situations, 1: the field dimensions and pipe diameter are unknown and the model designs both of them, 2: the field dimensions are known (i.e. partitioning of field is described by user) and the model will compute the pipe diameter and its related length according to the friction loss and farm layout. It is possible to select either one of the above mentioned scenarios after choosing manifold and lateral pipe within the main toolbox pipe design section. The model needs the following data to design the pipes: Hazen-Williams coefficients for manifold and lateral pipes, the speed limit of water in manifold and lateral pipes, field slope in manifold and lateral pipe direction, emitter characteristic equation coefficients, maximum and minimum manifold and lateral pipes ideal length, the increased percentage of the pipes' diameter due to clogging and so on. Figure 2 demonstrates the manifold and lateral pipe design tool box in which the user can insert information and data in. First, based on the emitter coefficient of variation and uniformity coefficient, the software calculates the pressure loss in an irrigation unit. Then, the obtained pressure loss will be divided relatively equal between manifold and lateral pipes.

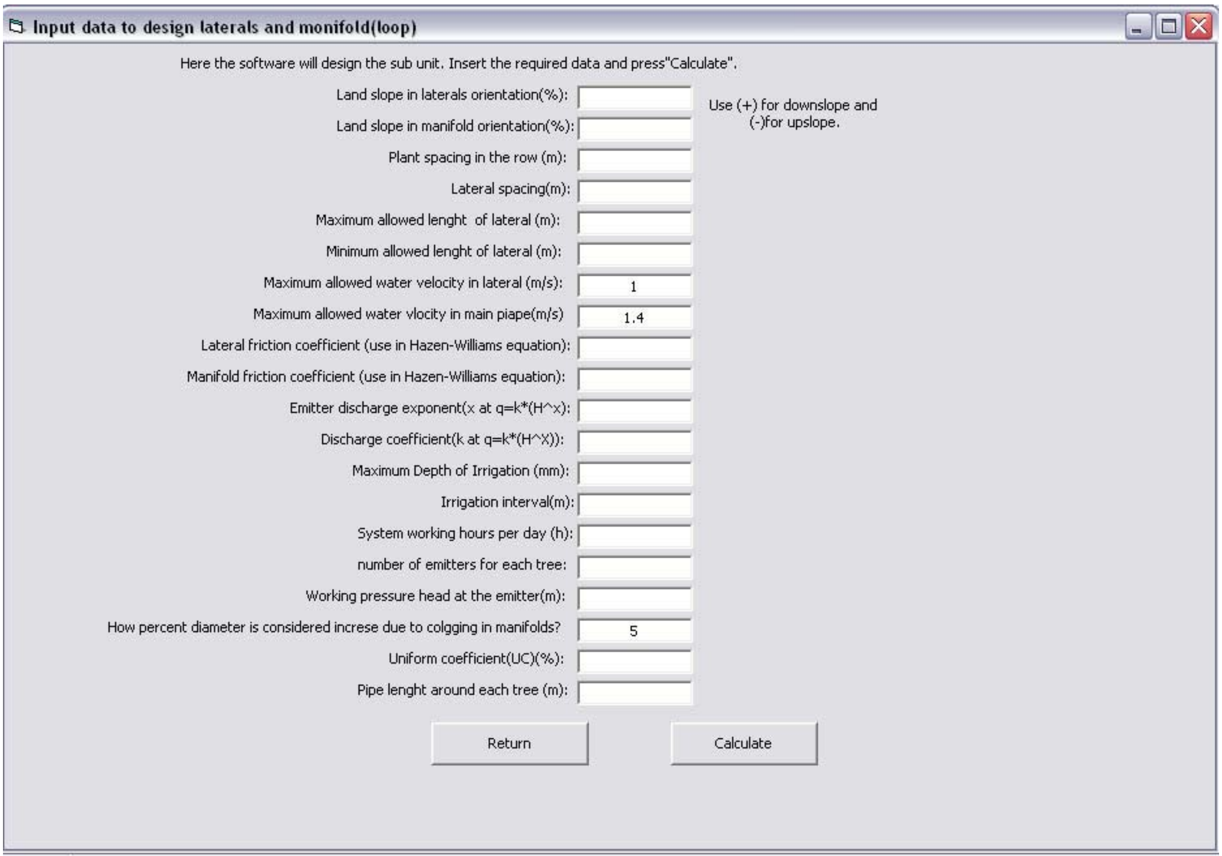

Fig. 2. The manifold and lateral pipelines design tool box

Based on input data, the model calculates the lateral pipe diameter and length along and against the slope direction. Also, the lateral pipe discharge, number of emitters, irrigation time, and the water speed in the lateral pipes (after designing) will be demonstrated to the user. Figure 3 shows an output tool box information for the final result of the field subunit hydraulics design of the manifold, lateral pipe design, required devices (apparatus), and fitting list.

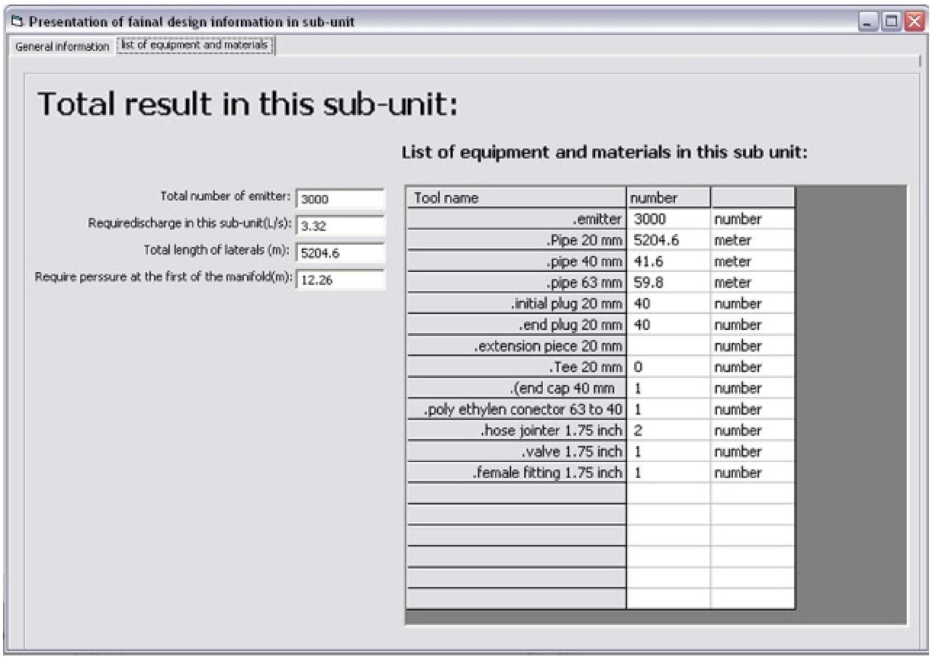

Fig 3. An output tool box information for the required devices and fitting

Since discharge is decreased along the manifold pipe, it is beneficial for the manifold pipe to be designed telescopically (the pipe diameter is reduced from the beginning to the end at two in three sections through the pipe length).The model could design the pipe in one or two diameters. In this section all the information required for performing the design in the field, such as device name, size and number of required components and fitting is reported to the user. Then the software will design partitioning of manifolds, and the diameter and length of the main pipe segments. As the discharge decreases during the line, economically it is beneficial that the pipe diameter decrease along the line. Reduction in diameter should be in a way that head loss will not increase the allowable head loss for the system. In a situation in which all manifolds are operating simultaneously, the pipe diameter and the related length will be computed and reported to the user. When the manifolds are partitioned, discharge in different distances and partitions will be calculated by the software, then based on this data the main pipe is designed. In other words, this process has several steps in which at each partition the discharge at different parts of the pipe are calculated. Then, considering the hydraulic parameters the main pipe diameter is designed in each part and then compared to each other and the biggest diameter is selected as the last design. After designing the main pipe, the software calculates the pressure head loss and adds all the minor head loss due to the fittings. Finally, according to the differences in elevation at the beginning and end of the pipes, head loss along the main, manifold, and lateral pipes, the required pressure at the beginning of the pipe at each partition will be determined, and then the user will be able to select a proper pump for the system. As the pipe diameter increases the pressure head loss decreases, and consequently a pump with lower power and lower cost is needed for operating the micro irrigation system. The MIDS software will perform economical analysis to demonstrate the better choice.

Amount of energy consumption and its cost are other important criteria in designing the micro irrigation system. In this software, the amount of energy consumption is determined using the power and operating hours of the pump that are chosen by the software program for different months. Figure 4 shows the output page that indicates the economical analysis and the cost of project.

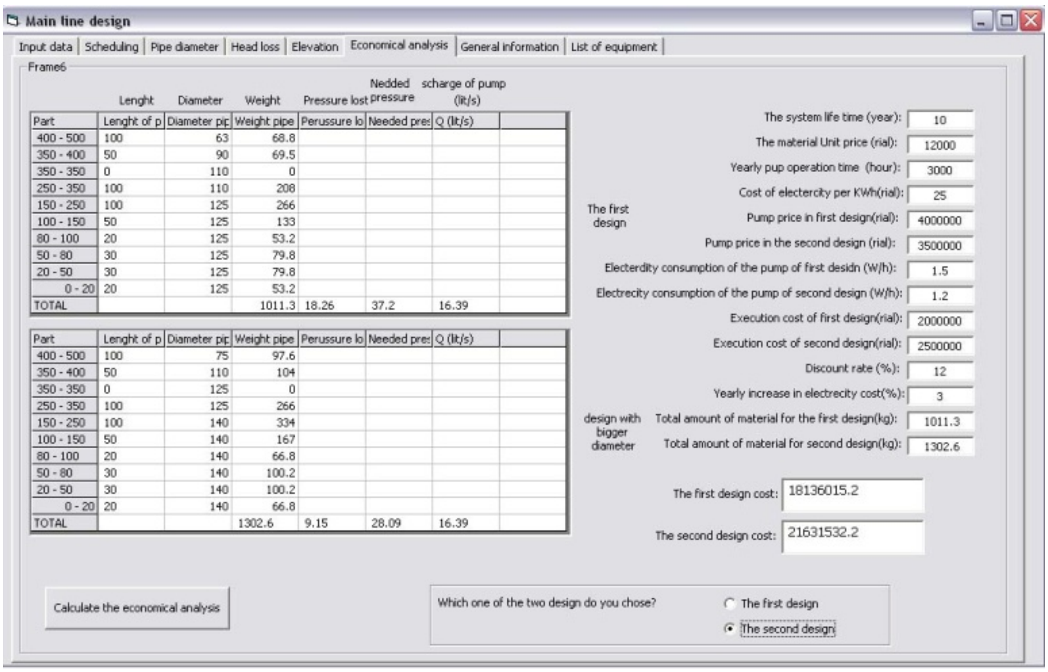

Fig. 4. An output page of the economical analysis and the cost of project

In many countries the electricity power cost is increased annually. In addition, for each consumption period, the consumption rate increases as a non-linear function of consumed energy. Furthermore, during the summer peak times the cost of energy is more expensive.

To calculate the cost of electricity energy consumption the cost of energy in the present year and the discount rate (rate of inflation) for future years should be entered to the model.

According to the irrigation water requirement in different months, the operating hours of the pump is calculated and with regards to the rate of energy consumption, the energy cost at each two month interval is calculated by the model. In addition, an increase in electricity price and its value for the increment consumption for the future are estimated by the model. Then the model uses cost value for economical analysis (net present value method) to predict the total energy cost (along system life time) and changes to the present value.

4. CASE STUDY

To evaluate the model, it is necessary to compare the results obtained from the model with existing projects in different climates, areas, crop cultivation and topography conditions. One of the projects evaluated by this model is described below.

An irrigation project under micro irrigation system in a 10 hectare orange garden with silty loam texture soil was selected for evaluation of MIDS model. The distance between trees was 5 meters in each direction. Table 1 shows the comparison of some designed parameters obtained by model and the specialist designer.

Table 1. Design parameters determined by expert and the MIDS model

Parameters	Designer	Software
Max. Eto (mm/day)	6.44	5.92
crop coefficient	0.99	0.95
Max.Transpiration(mm/day)	no-report	5.5
Max. Irrig. Water(mm/day)	no-report	7
Wetted Area(%)	19	19
Emitter per plant	6	6
Emitter pattern	single row	single row
Emitter spacing (m)	1	0.96
Irrig. time (hr/day)	8	10
Lateral diameter (mm)	16	16
Lateral length (m)	no-report	60
$CaCO_3$ Precipit. Probe	no-occur	no-occur

According to the well position (Irrigation water Source) and garden shape, based on required input data the model was run and the MIS design parameters were determined. These parameters consisted of 23 pieces of main pipes (110, 90 and 75 mm diameters) at different parts of garden, 20 pieces of manifolds (50 mm diameter), required system inlet pressure, 41m (≈ 4 atm.) and the pump power consumption, 10 kWh. The average irrigation times for the system were 6.5, 8, 4.5 and 2 hours in spring, summer, fall and winter respectively. The initial and operation cost (equivalent cash flow or Fabrication cost) was determined about 20,000,000 Rials/ha for this project.

Since the economical analysis in micro irrigation design is not considered by most designers, the model optimized the MIS design projects economically. To economically analyze the aforementioned project costs, the MIDS was run with those required input data obtained from the project and the Present Project Cost (preliminary cost) was determined. Then, the MIDS offered the larger pipe size diameter to user in order to determine the Optimized Project Cost with regard to electricity cost, pipe weight, pipe price, pipe shelf lifetime and total-use consumption of electricity (energy) use by micro irrigation system. The Optimized Project Cost was determined as shown in Table 2. The results show that the initial and operation cost for the preliminary simulation (Present Project cost) is 20000000 Rials which is similar to the cost suggested by the specialist designer (Table 2). On the other hand, the initial and operation cost using the larger size of pipe for the optimized project cost was determined 220000000 Rials. Considering the energy cost for both simulations indicates that the Total Optimized Project Cost was less than the Total Present Project Cost. The results in output file show that piping with one size larger was more economically efficient.

Table 2. The present and optimized project costs (Rials) for system

	Present project cost	Optimized project cost
Initial and operational cost	200000000	220000000
Present value of power cost	458,957,304	407,473,832
Total cost	658957303.7	627473832.2

In addition, several projects were also simulated by this model and results showed that some changes in diameters of main and sub main pipelines can reduce the total cost of the system caused by lowering energy consumption. These costs are further highlighted in new economical conditions after elimination of the Iranian government subsidiary payment for electricity.

Although this evaluation was performed for a 10 hectare garden, it is expected that a larger amount of cost reductions will take place in larger field size. This application makes this software more useful to find a more economically efficient micro irrigation system in any MIS design projects.

In order to compare the technical design of pipes (primary pipes designed by the model) and the economical design of pipes (pipes in one size greater than technical pipes diameter designed by model) as design 2 and design 3 respectively, with the other alternative designs, 2 more projects were examined. In the first project (first alternative design, as design 4) it was assumed that the diameter of pipes was 1 size larger than the economical pipe design. In the second project (second alternative design, as design 1) the diameter of pipe was assumed to be 1 size smaller than the technical pipe design. Figure 5 shows the results of all simulation projects cost. In case of smaller pipe diameter design (design 1), as pipe diameter size is increased, the head loss decreased, but the weight of pipe is increased, which caused the initial price to increase slightly. For example, if pipe diameter is changed from 63 mm to 75 mm, pipe thickness increased up to 7 mm and pipe weight increases by 300 $gr.m^{-1}$ (for standard, pipe PE63).

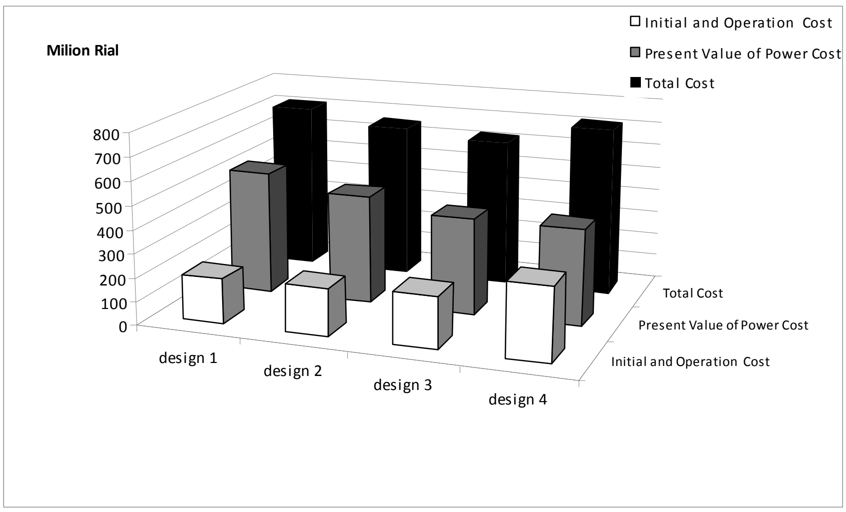

Fig. 5. Initial operation cost, present value of power cost, and total cost for designs 1 to 4

In case of selecting larger pipe diameter (design 3 and 4 with pipe diameters one and two sizes larger than the technical size respectively) for the project, as the diameter increased the amount of pipe material and weight of pipe build up considerably and this simulation drove up the pipe price dramatically. For instance, if the pipe diameter increased from 140 to 160 mm, the thickness increased 11 mm and caused the pipe weight to increase up to approximately 1 kgm^{-1}, then the initial cost in design 4 becomes much more expensive than the design 3 (Fig. 5). Based on such pipe analysis, the smallest pipe diameter (design 1) is not technically recommended because of high water velocity and head loss in the pipe resulting in the use of the more powerful pump, which increases the electricity consumption and its cost for this project. The results indicated that the design 3 (economical design) among the others is more economically efficient. Finally, it is recommended that the micro irrigation designer (particularly in Iran) analyze the economical aspect of any MIS projects. With respect to the aforementioned discussion it is noted that the MIDS is not only able to design the micro irrigation system but also examined the economical analysis of micro irrigation system efficiently.

5. CONCLUSION

Considering the results obtained from the MIDS and the specialist designer it is concluded that the software gives acceptable results with high reliability to design micro irrigation system. Results indicated that concerning the cost of electricity in the life time of project, total optimized project cost in MIS can be reduced by enlarging the pipe (main and sub main) diameter. Software helps the user to calculate the diameter, length, weight, and cost of the pipe accurately, quickly, and easily. A user with limited knowledge about micro irrigation system can design such system quickly. There is complementary information, tables, curves, figures, and explanations available in the model that allow the user to design the micro irrigation system without the need for further information and the need to refer to other references. Also, if the user made a mistake in any part of the software, the software would notify the user through a message. Finally, it is recommended that the micro irrigation designer analyze the economical aspect of any MIS project. MIDS is a comprehensive and feasible program that can be used to design a micro irrigation system by experts and the unskilled at different field conditions for various crops. Also, it is able to examine the economical analysis of pipelines in micro irrigation systems efficiently.

REFERENCES

1. Ghaemi, A. A. & Hosseinabadi, Z. M. (2004). Glance at water resources and pressurized irrigation system. *Proceeding of The 3rd Seminar of Khuzestan Regional Committee on Irrigation and Drainage*. Pressurized Irrigation System. Jan. 6&7. Khuzestan, Iran.
2. Frooghi, F. & Ghaemi, A. A. (2004). Determination of wheat optimal irrigation depth for different management strategies in center pivot irrigation. *Journal of Science and Technology of Agriculture and Natural Resources*. Isfahan University of Technology, Isfahan, Iran, Vol. 9, No. 2, pp. 1-15.
3. Ghaemi, A. A. & Chieng, S. T. (1995.). Effect of number, location, and degree of clogged emitters on hydraulics of micro-irrigation system. Paper presented at *ASAE, 50th Annual Regional Conference, Pacific Northwest Section ASAE*, Harrison Hot Springs Hotel, B.C., Canada.
4. Ghaemi, A. A., Rafiei, M. R. & Sepaskhah, A. R. (2009). Three-temperature monitoring for frost protection of orchards in semi-arid regions using sprinkler irrigation. *Agricultural science in China*, Vol. 8, No. 1, pp. 98-107.
5. Molina-Martíneza, J. M. & Ruiz-Canalesb, A. (2011). Pocket PC software to evaluate drip irrigation lateral diameters with on-line emitters. *Computers and Electronics in Agriculture*. (WWW.intechopen.com).
6. Cook. F. J, Fitch, P., Thorburn, P. J., Charlesworth, P. B. & Bristow, K. L. (2006). Modeling trickle irrigation: Comparison of analytical and numerical models for estimation of wetting front position with time. *Environmental Modeling & Software.*, Vol. 21, Issue 9. pp. 1353-1359.

7. www.academia.edu. (2009). Computer aided design of trickle of irrigation systems. Meshkat and Warner, 2006.
8. www.Engineering.usu.edu. (2008). Allen et al. (2007)
9. Jaafarnejad qomi, A & Abbasnejad, R. (2006). *Step by step visual basic training*. First edition, Rayaneh sciences publisher, p. 354.
10. Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. (1998). Crop evapotranspiration guidelines for computing crop water requirements. Rome, FAO.
11. Keller, J. & Bleisner, R. D. (1990). *Sprinkler and trickle irrigation.* New York, Van Nostrand Reinhold, p. 652.
12. Nakayama, F. S. & Bucks, D. A. (1986). *Trickle irrigation for crop production design, operation and management.* Amsterdam: Elsivier, p. 383.
13. Alizadeh, A. (2007). Irrigation system design, pressurized irrigation system design. Vol. 2, Ferdowsi University of Mashhad, p. 267.
14. Zor. B. & Schowartzmass, M. (1985). Emitter spacing and geometry of wetted soil volume. *Journal of Irrigation and Drainage Engineering*. ASCE, Vol. 112, No. 3.
15. Christiansen, J. E. (1942). Hydraulics of sprinkling system for irrigation. *Trans. American Society Agriculture Engineering*, Vol. 16, No. 6, pp. 1108-1116.
16. Feng, J. & Wu, I. P. (1990). A simple computerized drip irrigation design. *Proceedings of the Third National Irrigation Symposium*, Phoenix, AZ., pp. 348-353.
17. Sadeghi, S. H., Mousavi, S. F., Eslamian, S. S., Ansari, M. S. & Alemi, F. (2012). A unified approach for computing pressure distribition in multi-outlet irrigation pipelines. *Iranian Journal of Science & Technology, Transactions of Civil Engineering*, Vol. 36, No. C2, pp. 209-223.
18. Ghaemi, A. A. (2000). Clogged emitters and hydraulic characteristics in micro-Irrigation system laid on Flat and slopped terrain. *Proceeding of the International conference on micro and sprinkler irrigation system*, Jalgaon (Maharshtra)-India.