ESTIMATION OF WATER SUPPLY COSTS AT VARIOUS PRESSURE LOSSES IN LATERAL PIPES IN CLASSICAL SPRINKLER IRRIGATION SYSTEM

EVALUATION DU COUT D'APPROVISIONNEMENT EN EAU AUX DIVERSES PERTES DE PRESSION DANS LES TUYAUX LATERAUX DU SYSTEME CLASSIQUE D'IRRIGATION PAR ASPERSION

Sonia Zebardast[1], Ali Rahimi Khoob[2] and Isaac Rahimi[3]

ABSTRACT

Large pressure variation in sprinkler irrigation pipes increases operating pressure, results in non- uniform water distribution, high energy costs and water losses. If pressure variation were reduced, irrigation uniformity would be better, operating pressure would reduce but the pipe cost would be higher. In this study sample fields of manually moved sprinkler irrigation system were designed with allowable pressure variations of 5, 10, 15, 20, 25, and 30% to cultivate alfalfa in Khuzestan. The cost of water supply was estimated for the above fields considering current and primary costs in the year 2009 and at different interest rates. Results showed that at low interest rates, designing for 15% pressure variation and at high interest rates designing for 25% pressure variation were most economical.

Key words: *Sprinkler system, pressure variation, non uniform distribution, friction loss.*

RESUME ET CONCLUSIONS

La grande variation de pression dans les tuyaux d'irrigation par aspersion augmente la pression d'exploitation. Cela résulte en distribution non uniforme, coûts élevés d'énergie et pertes d'eau. Si la variation de pression est réduite, l'uniformité d'irrigation sera meilleure, la pression d'exploitation réduira, mais il augmentera le coût de tuyau. Dans cette étude, ont été conçus les champs d'échantillon du système portable d'irrigation par aspersion utilisant les variations admissibles de pression de 5, 10, 15, 20, 25 et 30 % pour cultiver la luzerne

1 Master science student of Irrigation and Drainage, University of Tehran, college of Aboureihan, Iran; E-mail: Sonia_zebardast@yahoo.com
2 Associate professor of Irrigation and Drainage, University of Tehran, college of Aboureihan, Iran; E-mail: akhob@ut.ac.ir
3 Master science student of water resources engineering, Shahid Bahonar University of Kerman, Iran; E-mail: Isaacrahimi@yahoo.com

dans Khuzestan. Le coût d'approvisionnement en eau de ces champs a été évalué sur la base des coûts actuels et principaux de l'année 2009 aux taux d'intérêt différents. Les résultats ont montré qu'au taux d'intérêt bas, la conception de la variation de pression de 15 % et qu'au taux d'intérêt élevé la conception de variation de pression de 25 % étaient les plus économiques.

Mots clés : *Système d'irrigation par aspersion, variation de pression, distribution non uniforme, perte de frottement.*

1. INTRODUCTION

Iran is an arid to semi-arid country where lack of rainfall and water restricts agriculture, which is the largest water consumer. In recent years, more attention has been paid to the development of sprinkler irrigation systems because they allow more efficient and uniform water distribution in the field than surface irrigation. Besides, they are adaptable to varied land topography and soil types.

As a thumb rule, the water pressure variations in sprinkler pipes should not exceed 20% (Salamat and Tavakoli, 1999, Alizadeh, 2004, Monserrat 2009, Najafimood 2005, Valiantzas and Decras 2004). Studying the effect of different allowable ranges of pressure changes is important for working out the costs of sprinkler irrigation system. Pressure variation in the sprinkler pipes governs sprinkler performance and it can be adjusted by proper designing of the pipe length, diameter, operating pressure, etc. For example, small diameter pipes will reduce pipe cost but will lead to more non-uniformity and loss of valuable irrigation water, whereas, a larger diameter pipe will reduce pressure variation and losses but will increase the pipe cost (Martinez.et.al 2004, Romero.et.al 2006). In the present study, six sample fields with manually moved sprinkler irrigation system were designed with water pressure variations of 5 to 30% with 5% incement for Khuzestan and their current and investment costs were estimated with interest rates of 7, 10, 15 and 20%.

2. MATERIALS AND METHODS

2.1 Data and Study area

Khuzestan province was the case study area that has vast fertilized plains and irrigation networks. However, inadequate water has been the most important constraint in agriculture in the recent years. This has attracted attention to the water saving sprinkler method of irrigation. The soil of the experimental region is silt loam and has a moisture holding capacity of 150mm per meter soil. The basic infiltration rate of the soil is 14 mm h^{-1} (CEC, 2003). Alfalfa, one of main crops grown in this region and with higher water need than the other plants, was selected for sprinkler design. The maximum water need of alfalfa is 7.52 mm day^{-1} (Alizadeh, 2000).

2.2 Field design

Lands area limit for the design was 2 ha > Area > 26 ha and usually between 10 and 15 ha (Tafazoli, 2004). According to the land ownership, farmers' cooperatives and cultivation practices, the most appropriate net area of alfalfa under sprinkler irrigation is 50 ha (CEC, 2003). This area was the basis for designing sample fields with manually moved sprinkler irrigation system, in order to determine diameters of main and lateral pipes, the pressure required for pumping station, number of working laterals and planning of irrigation. In this study, sprinkler laterals were placed along the contours and because central and southern plains of Khuzestan are flat, water pressure variation results only due to hydraulic load loss in pipes. The pressure at the head of lateral is obtained by following relation (Keller and Bliesner, 1990).

$$H0 = Ha + 0.75\ Hf + Hr \qquad (1)$$

Where, H0 is the pressure at the head of lateral (m), Ha: average pressure of sprinkler (m), Hf: friction loss (m), Hr: riser height (m).

Friction loss was estimated from following relation (Keller and Bliesner 1990):

$$Hf = 7.89\times107\times (L/100) \times Q1.75\times D- 4.75\times F \qquad (2)$$

Where, Hf: pressure loss due to friction (m), L: lateral length (m), Q: entrance flow rate to lateral (l s^{-1}), D: internal diameter of lateral (mm) and F: Christiansen coefficient for pipes with several outlets.

A sprinkler with nozzle opening of (5.5mm × 2.5mm) and arrangement of 18 × 12 square meters was chosen for irrigation by using Tables of Keller and Bliesner (1990), considering the basic infiltration rate and net irrigation requirement in the peak water demand period. This sprinkler with water pressure of 35 m has flow rate of 0.62 l s^{-1} and inlet flow rate to lateral was obtained from the number and flow rate of sprinklers. Length of lateral was determined such that the friction loss in it was less than allowable limit. Allowable friction loss was obtained from (Tafazoli, 2004):

$$\Delta Ha = \alpha \times Ha \qquad (3)$$

Where ΔHa: allowable pressure loss in length of lateral (m), Ha: average operating (m) and α: percentage of pressure variations. Specifications of the fields and irrigation subunits are shown in Table 1 by different percentages of friction loss.

Table 1. specifications of fields and irrigation subunits (les spécifications de champs et de sous-unités d'irrigation dans de différents pourcentages de perte de friction dans lateral)

Friction loss (%)	Subunit area (ha)	Number of irrigation subunits	Field area (ha)	Length of lateral (m)	Flow rate of lateral (l/s)
5	3.8	14	53.22	126	6.79
10	4.84	10	48.38	162	8.64
15	5.53	10	55.3	186	9.87
20	6.22	8	49.77	210	11.11
25	6.91	8	55.3	234	12.34
30	7.26	6	43.55	246	12.96

In order to calculate friction loss in sub main and main pipes, Waterz and Keller's equation was used (Keller and Bliesner 1990). Flow rate in main and sub main pipes is obtained from the sum of flow rate required for pipes and branched irrigation. Diameter of main and sub main pipes was determined considering flow rate of the pipe. Gross water volume required annually was calculated by net requirement of irrigation (from a National Document), area of field and irrigation efficiency.

For different friction losses, the pressure at the lateral head, minimum pressure, pumping pressure and annual volume of water required were estimated (Table 2).

Table 2. Operating pressure, gross water volume and annual electricity consumption (les pressions de champs, le volume brut d'eau voulue et la consommation électrique annuelle des champs dans de différents pourcentages de perte de friction dans lateral)

Friction loss (%)	Pressure at the head of the lateral (m)	Minimum pressure of system (m)	Pressure required for the field(m)	Annual volume of water required for the field ($1000m^3$)	Annual electrical consumption (mw)
5	38.25	36.4	47.95	1056.49	205.51
10	39.52	35.98	45.59	965.17	183.99
15	40.66	35.6	48.06	1120.12	212.05
20	42.09	35.12	47.82	1020.85	204.13
25	43.81	34.55	49.87	1157.44	227.37
30	44.8	34.22	51.04	919.02	205.63

Irrigation efficiency was obtained from relation 4 (Tafazoli, 2004):

$$Ea = DEpa \times Re \times Oe \qquad (4)$$

Where Ea: water application efficiency (%), DEpa: distribution efficiency in terms of adequacy of irrigation (%), Re: effective part of distributed water (fraction) and Oe: water distribution efficiency (fraction).

DEpa based on adequacy of irrigation shows the relation between uniformity coefficient of distribution and adequacy of irrigation. Considering statistical correlation between the two, DEpa was obtained according to adequacy of irrigation from Tables (Keller and Blisner, 1990). According to design conditions and experiences, uniformity coefficient is recommended 85% for alfalfa and 80% for adequacy of irrigation (Tafazoli, 2004). Effective part of water distribution is 5 to 10% in general condition but at high wind speed, losses will be more and DEpa will be between 1 to 5 % in pipe lines (Keller and Blisner, 1990).

2.3 Costs

The costs have two components including investment costs such as purchasing, carrying and installing pipe and joints, irrigation, electrical and mechanical equipment, electricity and maintenance and labour (CEC, 2007). In order to determine investment costs, a complete list of necessary equipment (including irrigation, mechanical and electrical equipment) and their prices is prepared and the price of installing and implementing all elements was determined at 2009 price level. Primary investment costs were calculated considering the useful life of elements of irrigation system. Each of elements of irrigation system that has useful life less than project's life, their costs was renewed after completion of useful life. Current value of renewable costs was obtained from relation 5 (Alizadeh, 2004):

$$P = F/ (1 + i)^n \tag{5}$$

Where, P: current value of renewable costs, F: future value of renewable costs, i: interest rate and n: project's useful life

For comparing among the designs, the fixed investment costs is converted into annual costs, which were obtained by using relation 6 (Alizadeh, 2004):

$$A = P \times CRF \tag{6}$$

Where, A: annual value of fixed costs, P: present value of fixed costs, CRF: capital recovery factor, calculated by the following Alizadeh, (2004):

$$CRF = [i (1 + i) n / ((1 + i) n - 1)] \tag{7}$$

Where, CRF: capital recovery factor (fraction), i: interest rate (fraction) and n: project's useful life (year)

Annual current costs include annual costs of electricity, operation & and maintenance cost and labour cost. Cost of electricity was obtained by considering power of pumping station, annual operational hours and unit cost of electricity. Power of pumping station was obtained from relation 8 (Alizadeh, 2004):

$$P = (Q \times H)/ (102.2 \times E) \tag{8}$$

Where, P: power of pumping station (kW), Q: flow rate ($m^3\ s^{-1}$), H: pumping height (m) and E: motor-pump efficiency (%).

Annual electricity cost was obtained from pumping station capacity and annual operation hour (calculated as the ratio of gross water volume required to flow rate) and given in Table 2 earlier. The 2009 cost of electricity was Rials 773/kW. The O7M costs were taken as 1% of the cost of mechanical and irrigation equipment and 3% of the cost of purchasing electrical equipments (Keller and Bliesner, 1990).

Labour cost was obtained based on required labour, number of irrigations and cost of per hour (Rials 10,000 for each worker per hour in Khuzestan). Labour required in manually moved sprinkler irrigation system is 1.73 persons h^{-1} ha^{-1} (Tafazoli, 2004) The annual irrigation numbers was obtained from ratio of depth of annual gross water required to gross water depth in each irrigation. Annual total cost is the sum of annual investment costs, annual current costs and the price of water per cubic meter in each of fields. Basic interest rate of making credit of developmental plans is 7% in Iran but the costs with interest rates of 7, 10, 15 and 20% were evaluated because this value is not constant in Iran.

3. RESULTS AND DISCUSSION

The costs are divided in to two subsets: investment costs and annual current costs and are shown in Figure 1 for different percentages of friction loss and interest rate.

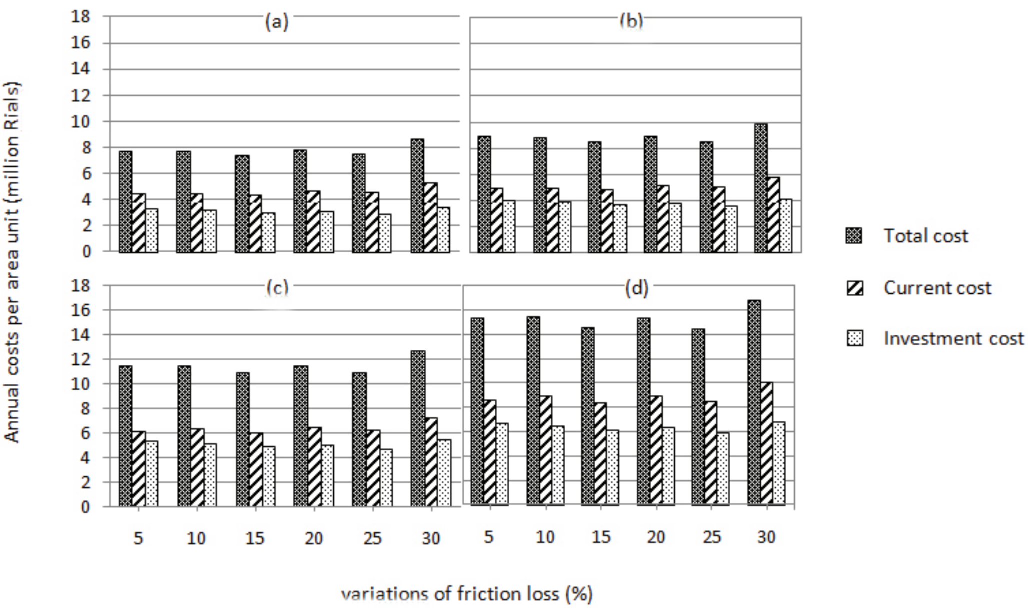

Fig. 1. Costs at interest rates of a) 7%, b) 10%, c) 15% and d) 20% (le total annuel, le courant et l'investissement coûtent dans de différents pourcentages de perte de friction et de taux d'intérêt. a) 7 %, b) 10 %, c) 15 % et d) 20 %)

The highest annual total cost at all interest rates is related to 30% friction loss and the least is related to 15% friction loss at 7and 10% interest rates and 25% friction loss in 15 and 20% interest rates. The least annual current cost at all interest rates is for 15% friction loss and the least annual primary investment cost is for 25% friction loss. Annual total cost at friction losses of 5, 15, and 25% is less than that at 20% friction loss.

Water price per cubic meter is given in Table 3 in different percentages of friction loss and interest rates and is shown in Fig.2.

Table 3. Water price (Rials/m^3) at varying friction loss and interest rate (le prix d'eau par mètre cubique (rial) dans de différents pourcentages et des taux d'intérêt)

Percentage of friction loss	Interest rate			
	7%	10%	15%	20%
5	388.63	447.60	578.53	773.48
10	385.24	443.88	575.54	774.12
15	364.92	418.64	538.53	718.23
20	379.42	434.76	558.99	746.37
25	356.77	406.89	519.36	689.07
30	409.56	468.15	599.98	799.05

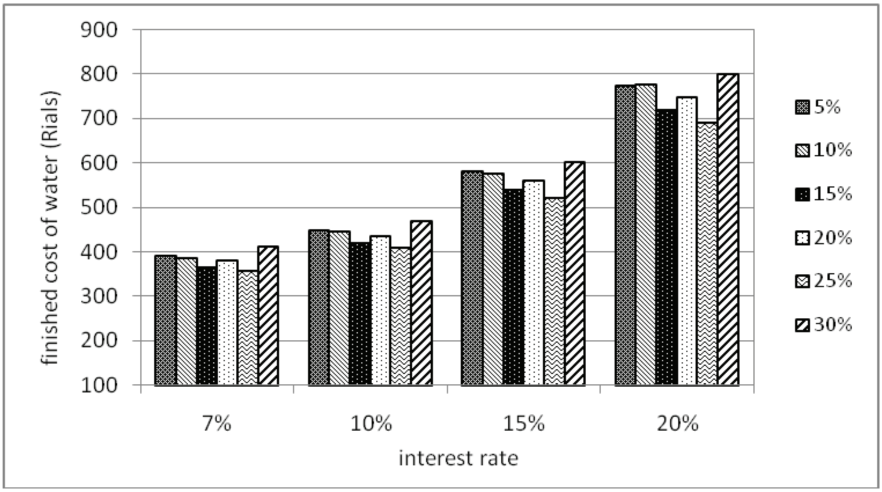

Fig. 2. Cost of water for different percentages of friction loss and interest rate (le prix fini d'eau dans de différents pourcentages de perte de friction et de taux d'intérêt)

As shown, with increasing interest rate, cost of water has increased and high interest rates will have low profitability of the networks. The least water price calculated in all interest rates is at 25% friction loss and this price in 15% friction loss will be less than the price in 20% friction loss. The highest water price in all interest rates is related at 30% friction loss.

4. CONCLUSIONS

The least annual total cost per area unit would be Rials 7.39 and 8.48 million at 7 and 10% interest rates for 15 % friction loss and Rials 10.87 and 14.42 million at 15 and 20% interest rates for 25% friction loss.

The least water price per cubic meter of Rials 356.77, 406.89, 519.36 and 689.07 at 7-20% interest rates is for 25% friction loss.

The difference in annual total cost between 15 and 5% friction losses at different interest rates is Rials 0.5 to 0.15 million per area unit for larger areas.

Considering that the water cost in 15% friction loss is less than that in 20% friction loss, it can be concluded that in low interest rate situation, the design operating pressure be selected to allow a maximum of 15% friction loss and in high interest rate situation, selecting operating pressure to allow a maximum of 25% friction loss may be appropriate for manually moved sprinkler system.

This study was done for alfalfa in Khuzestan and for manually moved sprinkler system. Based on the study, it may be concluded that in order to improve sprinkler irrigation design, the combination of operating pressure, friction loss and crops should be optimized. In this study, 5 to 30% pressures have been considered by 5% increment. It is recommended that the appropriate percentage of friction loss to be determined before designing plans.

REFERENCES

Alizadeh, A. 2004. designing irrigation systems. university press of Imam Reza.

Alizadeh, A. 1998. net requirement of crop and garden products' irrigation in Iran.

CEC, 2007. Consulting engineers' Company of Mahabghods. report of agricultural bank and financial evaluation of Dasht-e Abbas network. 60 pages.

CEC, 2003. Consulting engineers' Company of Mahabghods. 2003. report of studies about integration and exploitation system from sources of Khouzestan. 300 pages.

Keller, J. Bliesner, RD. 1990. Sprinkler and trickle irrigation.newyork ,n.y:van nostrand reinhold.

Martinez, J. Martinez, R. Tarjuelo. 2004. Analysis of water application cost with permanent set sprinkler irrigation systems. Irrigation science. 23 : 103-110.

Monserrat, J. 2009. Allocation of flow to plots in pressurized irrigation distribution networks: analysis of the Clément and Galand method and a new proposal. Irrigation and drainage engineering. 1 : 1-6.

Najafimood, M. 2005. designing pressurized irrigation systems. press of Birjand University.

Romero, J. Martenez, J. Martnez, R. Tarjuelo, J. 2006. Set Sprinkler Irrigation and Its Cost. Irrigation and drainage engineering. 5 : 445-452.

Salamat, A. Tavakoli, A.1999. principle of sprinkler irrigation.

Tafazoli, M. 2004. technical standards of pressurized irrigation. publication of management and planning organization of the country. 233 pages.

Valiantzas, J. Dercas, N. 2004. Economic Design of Center-Pivot Sprinkler Laterals. Irrigation and drainage engineering. 6 : 491-498.