Research Article

Optimization and Modelling of Pressurized Irrigation Networks

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Abstract

The agriculture holds the biggest share of the water consumption. Thus, design of irrigation networks which is vital for agriculture becomes very important for water conservation. Among the different types of irrigation network systems, the most efficient irrigation method is known as the pressurized irrigation. This study aims to better understand how to design and model a pressurized irrigation network. An Excel VBA (Visual basic for application) program is coded for optimization with the first formula of Clément. "Network Optimization" program which uses the same method but there is limited input section is used to control the output. So, the importance of how the minimal changes in input gives big differences in output is revealed.

Keywords: *pressurized irrigation network, optimization, modelling, Clément formula*

Öz

Su tüketiminde en büyük pay tarım sektöründedir. Bu sebeple sulama şebekelerinin tasarımı, suyun korunumu dikkate alındığında çok önemli olmaktadir. Farklı yöntemlerle tasarlanan sulama sistemleri arasında en verimli yöntem basınçlı sulama olarak bilinmektedir. Bu çalışma basınçlı sulama sistemlerinin tasarım ve modellenmesini incelemek amacıyla yapılmıştır. Bu araştırmada Excel VBA kodlama dili kullanılarak, 1. Clément yöntemi ile basınçlı sulama sistemlerini optimize eden bir program üretilmiştir. Devlet Su İşleri (DSİ)' nin kullanmakta olduğu ve aynı metod ile hesaplama yapan, MS-DOS ortamında çalışan, kullanımı zor ve sınırlı veri girişi yapılabilen "Network Optimizasyon" programı ile bu çalışmanın çıktıları karşılaştırılmıştır. Böylece, girdi olarak verilmesi gereken boru iç çapları gibi ufak detayların aslında sonuçlarda büyük farklar oluşturabileceği ortaya konulmuştur.

Anahtar sözcükler:*basınçlı sulama şebekesi, optimizasyon, modelleme, Clément formülü*

Introduction

In the graphic of Food and Agriculture Organization of the United Nations (UN FAO), it is mentioned three major consumer sectors as agriculture, industry and municipal sector. (FAO, 2010; Figure 1). Water resources have been consuming substantially during agricultural operations. In 20th century, up to 1980's in many countries, particularly in developing countries, irrigation has developed rapidly in order to meet food demand. For this reason, the amount of irrigated land on the world has increased dramatically. Truthfully, it is assumed that agriculture is the largest consumer of water resources and accounts for 80–90% of all freshwater (Shiklomanov, 1998).

The continuous increase of water consumption in connection with rapid human population growth leads to reduction of water consumption per capita. Unfortunately, only the 20% of human population has access to the freshwater. According to the World Health Organization (WHO) in 10 years, water supply per capita is going to be 1/3 of today's supply and 3.5 billion people, approximately half of the world population, will not have an access to clean water resources (Onda et al., 2012).

The irrigation method is very important not only for productivity of agricultural land but also for conserving water resources. The main objective of the irrigation system is to provide the demanded water at peak level.However, the application cost for advanced irrigation systems to the land is very problematic. Therefore, searching suitable irrigation system have enforced the development of advanced and modern irrigation technologies and optimization methods.

By the invention of cheap plastic pipes in 1970s, the pressurized irrigation systems spread all over the world and lead to innovate new optimization methods. The main expense of any pressurized irrigation network is the cost of pipes. Because, the size of pipes are directly related with pipe prices, it is needed to the optimization ofpipe sizes. Therefore, many researchers formulated an objective function leading to minimize the construction of the irrigation network capital and operating cost. However, the optimal design of the irrigation distribution systems is a process involving not only cost but also performance (Khadra et al., 2014).

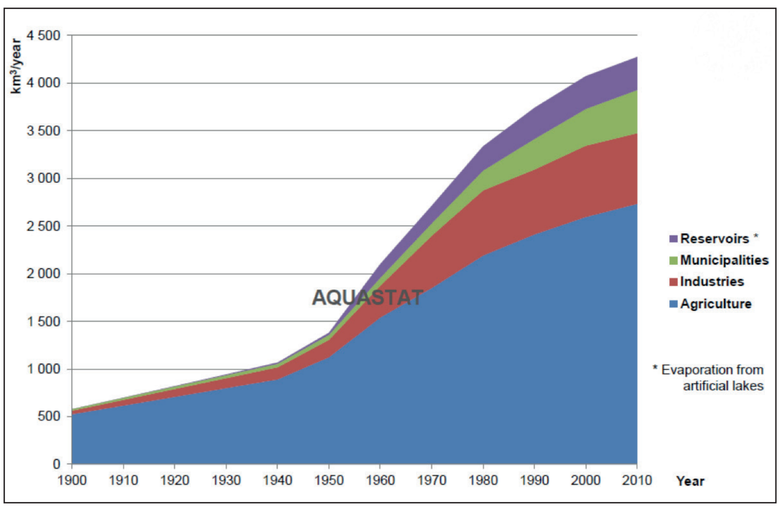


Figure 1. Estimated world water use by sectors (FAO-Aquastat (2010).

The demand of the irrigation system also depends on the probability of the number of user simultaneously using a hydrant. Clément (1966) used the probability of the irrigation network capacity being exceeded or fall behind when a user operates the hydrant. According to his method, the number of hydrants being open simultaneously is considered to follow a binomial distribution.

Actually, operating a hydrant, which is the outlet of the irrigation system, at different time and at different place is uncertain. Furthermore, the downstream hydrants on demand pressurized irrigation systems should be designed for a fixed upstream pressure head because they are affected more than the upstream hydrants (Khadra et al., 2014).

The increase of on demand and large scale irrigation systems in the early 1960s in France, leaded the development of statistical models to compute the design flows. The most used models are the first and the second Clément formulas (1966). But only the first formula of Clément has been widely used because of its simplicity and accuracy (Lamaddalena and Sagardoy, 2000).

The main step of designing on-demand irrigation network is the discharge calculation in each section (line) (Labye et al., 1988). In order to obtain the design flow, Clément used the average water demand in the irrigation system. Designing each line and hydrant by their own crop and the water demand could be possible in a small area but generally these network systems are designed for large scale croplands. Moreover, in a district, all the farmers generally grow same or similar type of crop. Thus, instead calculating each line and each parcel by different flow demand, using an average water demand in an irrigation project is logical.

This work purposed to perfectly understand the hydraulics calculations required for pressurized irrigation network. There are numerous hydraulics formulations necessary for optimization and hydraulic calculations. By realizing there is not a contemporary program for solving the pressurized irrigation network, an Excel VBA program is also coded. This code is named as EPNO (Excel Pressurized Network Optimization) to not repeat the long words in the manuscript a lot of times. Network Optimization Program, which is an optimization program used in the Mediterranean countries including Turkey, is used to compare the results from EPNO.

Irrigation

The Republic of Turkey the General Directorate of State Hydraulic Works (DSİ) defines the irrigation as supplying the moisture which is necessary for the vegetation growth in the effective root depth without damage to the soil structure efficiency with minimum waste of water and soil and with minimum labor. This definition shows that the irrigation should be planned very well because the water is a need for crop growth although it could also be harmful. In addition to that, the water waste should be minimized and an operational irrigation system should be well planned to deliver the demanded amount of water at the right time.

All farmlands have their own specific characteristics and all the farmers have their own farming traditions. This variety leads to many types of irrigation systems. Understanding the severity of water scarcity leads the researchers to focus on water conserving. There are many studies states that more than demanded amount of water is lost in surface irrigation methods. These researches leaded to invention of new irrigation methods such as sprinkler irrigation and drip irrigation. The sprinkler system is first introduced to the world in the 1930s and the drip irrigation method is invented in the 1960s. Both systems require pressurized irrigation network for their outlets to work accurately. The sprinkler and the drip irrigation are still the most efficient irrigation methods (Figure 2).

Pressurized Irrigation System

People tried different types of irrigation methods but seeking the most efficient method and the closest to the natural irrigation leaded to invention of the sprinkler system. The sprinkler system requires the pressurized irrigation network to run the sprinkler heads which is on the top of a sprinkler system and needs water pressure to turn the sprinkler's nozzle. Thus, the sprinkler's head makes the irrigation as like as rain. So, the crop gets the water in a natural way.

In an irrigation project, there is no way to shortage the amount of water that is demanded by the crop. So, the water conservation is needed to be involved in: storage, delivery, distribution, operation and application.

Pressurized irrigation system is more efficient than the traditional surface irrigation methods. The main advantages of the pressurized systems are: water consumption, area saving, less labor need, productivity, erosion control and crop protection. Transition to automation i.e. remote monitoring and controlling, is applicable to the pressurized system especially in need of metered water distribution.

Figure 2. Sprinkler and drip irrigation (DSI, 2009).

Material and Method

Computation of the Pressurized Irrigation System

The fluid mechanics have three main equations as follows: continuity, momentum and energy equations. For the high pressure irrigation flow is said to be steady, uniform and incompressible. Under these estimates continuity (1) and energy (2) equations, which are used mostly in the calculations of pressurized irrigation systems, are as follows:

$$Q = A_1 \times V_1 = A_2 \times V_2 = A_n \times V_n \tag{1}$$

$$V_1^2 / 2g + P_1 + Z_1 = V_2^2 / 2g + P_2 + Z_2 + h_f \tag{2}$$

Q: Discharge (ls-1) in Canal or Pipe

Ai: Cross Sectional Area (ha) of Pipe or Canal

Vi: Mean Velocity (m/s) of Pipe or Canal

g : Gravitational Acceleration (m/s2)

P : Pressure (metres of water column, m)

Z: Elevation above arbitrary datum (m)

hf: Head loss due to friction or turbulence between sections 1 and 2 (m)

The most important problem for the on-demand irrigation systems is the calculation of the network discharges. Because, the cropping pattern, meteorological conditions, the irrigation method and the farmers' behavior affects the demand. For a short term, which is generally the most arid month, designers consider the peak demand (Irrigation module) for an average cropping pattern for the whole irrigation area. The irrigation module, "q" [l s-1 ha-1] is the main determinant for the calculation of the discharges. Unfortunately, an individual cropping pattern may differ from the designed one. As a result, the discharge may be underestimated or overestimated. Many researches state some empirical methods to solve this problem. For instance, US Bureau of Reclamation (1967) advices to solve each project on individual basis and gives only general indications like: the maximum demand may be estimated at 125-150% of the average demand.

In the early 1960s, in France, the development of statistical models made the computation of the design flow of large scale on-demand irrigation projects easier. The most famous models are the first and the second Clément formula (1966) however only the first Clément formula has been widely used because it is easy to apply and most irrigation projects are projected for large scale area. This method is based on a probabilistic approach which states within a population of R hydrants, simultaneously open hydrants are considered to follow a binomial distribution (LaMaddalena & Sagardoy, 2000). Clément's first method: (Clément, 1966)

$$t' = \left(\frac{q_s A T}{R} \right) \Big/ d \tag{3}$$

$$\frac{t'}{T'} = \frac{t'}{rT} = \left(\left(\frac{q_s A T}{R} \right) \Big/ d \right) \Big/ rT = \frac{q_s A}{rRd} \tag{4}$$

p : The probability of an opened hydrant

tı: The average operation time of each hydrant during the peak period

Tı: Operating time during the peak period (hour)

r : Coefficient of utilization of the network (Tı /T)

T: Duration of the peak period (hour)

qs: Irrigation Module, 24 hours per day (l s-1 ha-1)

A: Irrigated Area (ha)

R: Total number of hydrants

d : Nominal discharge of each hydrant (l s-1)

The probability of an opened hydrant in a population of "R" homogeneous hydrants is "p" and the probability of a closed hydrant becomes "(1-p)". The hydrants which are being operated by the farmers are considered to be a random variable with binomial distribution.

So the mean and the variance:

$$\mu = pR \tag{5}$$

$$\sigma^2 = p(1-p)R \tag{6}$$

μ: Mean of opened hydrant in a population of "R"

σ^2: Variance of opened hydrant in a population of "R"

The cumulative probability, "Pq", among the "R" hydrants (Maximum "N" hydrants simultaneously operating):

$$P_q = \sum_{K=0}^{N} C_R^K p^K (1-p)^{(R-K)} \tag{7}$$

$$C_R^K = \frac{R!}{K!(R-K)!} \tag{8}$$

C_R^K : Combinations of "R" hydrants taken "K" at a time.

When "R" is large enough (R>10) and p > 0.2, the binomial distribution gets closer to the Laplace-Gauss normal distribution whose cumulative probability, "Pq", having a maximum of "x" hydrants simultaneously operating (-∞< x < N) is:

$$P_q = \frac{1}{\sqrt{2p}} \int_{-\infty}^{U(P_q)} e^{-\frac{u^2}{2}} du \tag{9}$$

"U(Pq)" is the standard normal variable corresponding to the probability "Pq", and "u" is the standard normal deviation given by:

$$u = \frac{x - Rp}{\sqrt{p(1-p)R}} \tag{10}$$

By solving equation 9 in series the exponential function “e-u²/2”, the relation between “Pq” and “U(Pq)” is tabulated (Table 1). Therefore, according to a prefixed value of “Pq” it is possible to determine the corresponding value for “U(Pq)”

Table 1: Standard normal cumulative distribution function

Pq	**0.90**	**0.91**	**0.92**	**0.93**	**0.94**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**
U(Pq)	**1.285**	**1.345**	**1.405**	**1.475**	**1.555**	**1.645**	**1.755**	**1.885**	**2.055**	**2.324**

Knowing “U(Pq)”, makes calculation the simultaneously being operated hydrant numbers, “N”, possible. For “u = U(Pq)” and “X = N”, from the equation 10, The first formula of Clément:

$$N = pR + U(P_q)\sqrt{p(1-p)} \quad (11)$$

The total discharge downstream of a specific section “i” is given by:

$$Q_i = pRd + U(P_q)\sqrt{p(1-p)Rd} \quad (12)$$

Qi : Discharge at the downstream of section i

p : The probability of an opened hydrant at the downstream of section i

R : Total number of hydrants at the downstream of section i

d : Nominal discharge of each hydrant (l s-1)

U(Pq) : The standard normal variable

After computing each section’s discharge, the designer can calculate the velocity at the flow on each sections however the inner diameter or the pipe type is still unknown. Computation the flow velocity requires pipe inner diameter.

There are many irrigation pipe producers in the world and they design the irrigation pipe in some specific standards. There are some important design criteria for the irrigation pipes such as: minimum velocity, maximum velocity, pressure class and inner-outer diameter or thickness. The producer should supply this information to the designer to choose the pipe by trial and error method via limiting the velocity.

The designer should be carefully balance the maximum velocity limit because higher flow velocity causes higher friction loss. As a result, there would not be enough pressure on the hydrants. For different pressure class of the irrigation pipe with the same inner diameter, the thickness or the outer diameter is different. For example, HDPE110 pipe at the pressure class 4atm (1atm=1.01325×105pa), the inner diameter is 104 mm and the outer diameter is 107mm, for the pressure class 8atm the inner diameter is still same but the outer diameter is 109mm.

After choosing the irrigation pipe size, the technician should calculate the maximum static pressure. It is a simple but very important calculation. Basically, subtracting the ground elevation at the node, from the head elevation gives out the maximum static pressure. In some cases, it is possible that between two nodes there could be a low elevation that requires more than the maximum static pressure calculated for the section between the nodes.

$$P_{static}^{node\,i} = H_{head}^{\max} - H_{ground}^{node\,i} \tag{13}$$

$P_{static}^{node\,i}$: Maximum static pressure at the node i (m)

$H_{head}^{\max}$: Maximum head elevation (m)

$H_{ground}^{node\,i}$: Ground elevation at the node i (m)

The last part of the pressurized irrigation system's hydraulic computation is maximum dynamic pressure, which is the pressure at the hydrants while system is operating. The maximum energy loss on the irrigation network occurs due to friction however advanced pipe technology produces pipes with very low friction coefficient.

There are several methods to compute the friction loss such as Colebrook and Manning Equations. Hydraulic slope, which is the friction loss per length, is used to calculate the friction loss. The hydraulic slope needs to be calculated for each section I preferred to use the Manning's equation.

$$Q_i = A_i R_i^{2/3} J_i^{1/2} n^{-1} \tag{14}$$

$$J_i = \left(\frac{Q_i n}{A_i R_i^{2/3}} \right)^2 \tag{15}$$

Qi : Section's discharge (ls-1)

Ai : Pipe's inner area discharge (m2) at section i

Ri : Hydraulic radius (m) at section i (Ri=Di/4 for full flow pipes)

Ji : Hydraulic Slope (m/m) at section i

n : Manning's friction coefficient (m)

Hydraulic slope, "J" shows the friction loss per meter so:

$$H_{Friction_i} = L_i J_i \tag{17}$$

$H_{Friction_i}$: Friction Loss (m)

Li : Section i's length (m)

Ji : Hydraulic Slope (m/m) at section I

There are also minor losses on the pressurized irrigation network. There are energy loss on the branches, hydrants, air intake valves, drain valves, and etc. These losses are very small according to the friction loss so they are negligible. Although they are very small, these minor losses become important for large scale irrigation systems. For each different type of irrigation network component there is a different minor loss coefficient. So, computation of these losses is harder. It is better to estimate an average minor friction loss than neglecting it.

$$H_{Minor_i} = K_M V_i^2 / 2g \tag{18}$$

H_{Minor_i} : Minor loss (m) at node i

KM : Minor loss coefficient (KM=1.5)

V : Mean Velocity (m/s)

g : Gravitational Acceleration (m/s2)

If there is any pressure breaker or pump on the network, the designer should take them in the calculation. The minimum dynamic pressure is the minimum pressure that is necessary for the sprinkler or dripping system to operate. At the hydrants' inlet there should be 35 m water column pressure for the sprinkler system. The head of the sprinkler requires 25 m water column pressure to work properly and there is an average 10 m local loss in a hydrant. For a large scale network (R>10), one hydrant with entrance pressure less than 30 m is negligible. Minimum dynamic Pressure:

$$P_{dynamic}^{hydrant,i} = H_{head}^{\min} - H_{ground}^{hydrant,i} - \sum H_{Friction_i} - \sum H_{Minor_i} \tag{19}$$

$P_{dynamic}^{hydrant,i}$: Minimum dynamic pressure at the hydrant i (m)

$H_{head}^{\min}$: Minimum head elevation (m)

$H_{ground}^{hydrant,i}$: Ground elevation at the hydrant i (m)

$\sum H_{Friction_i}$: Total friction loss from the pipeline start to the hydrant (m)

$\sum H_{Minor_i}$: Total minor loss from the pipeline start to the hydrant (m)

All these equations especially the first formula of Clément requires several parameters. These parameters, which their values are gained from DSİ are as follows:

Irrigation Module (q) [ls-1ha-1]: The amount of water in liter demanded by the crop in the peak term for a second in a hectare.

Irrigation Time [hour]: The average time of operation of the irrigation system for 24 hours (1day). For high Pressure irrigation systems, it is estimated as 20 hours. For pumped irrigation systems it is taken as 18 hours.

Net Area Factor: The total area should be decreased since it is going to be constructed on it and there will be a portion of the land is not going to be used for cropping. The net area factor is “0.873” for the piped irrigation systems.

The Standard Normal Variable U(Pq): It is also known as quality probability of the network. (U(Pq)=1.645)

Theoretical Parcel Area per Hydrant [ha]: The area for one hydrant. It is “8ha” for high pressure irrigation systems.

Hydrant Flow [ls-1]: The Flow that is going to be used in flexibility calculations for one hydrant. Depending on the theoretical parcel it is “10ls-1” for the high pressure irrigation systems.

Manning Friction Coefficient (n) [mm]: For HDPE and GRP pipes the manning friction coefficient is “0.009mm” (n=0.009mm).

Number of Hydrants without Flexibility: In an irrigation network, two hydrants with the same properties, one of them is at the upstream and the other is at the downstream, the upstream one has bigger probability of the use of demanded water than the other one. In order to fix this problem at the end of the pipelines for a specific amount of discharge (80 ls-1) or for a number of hydrants (4) the discharge is calculated by linear method (Q=Anet*q). In some situation, it is possible that the discharge calculated from the first formula of Clément’s is bigger than the linear method. In this case, the higher discharge should be assigned for the hydrant.

Excel Pressurized Network Optimization Code

However, there is a big demand for pressurized irrigation network constructions, there is not a very good pressurized irrigation network optimization program in use. DSİ uses a MS-DOS (Micro Soft Disk Operating System) program named Network Optimization Program which is an out-of-date program and it has some shortages. For example, there is no option to add all the pipes in production. So the results are not applicable to the produced pipes. Additionally, it requires too much time to prepare the input file and to understand the output file since it gives out messy outputs. Node assignment in the NOP is also a waste of time by itself.

For these reasons, a code written in excel visual basic which allows the user to work on the tables easily should be very helpful. Firstly, the coding should do node assignment by itself. It should calculate some input data by itself which NOP does not. It must have all the pipes in production and in need to add more pipes it must allow the user to input more pipe data. The program should allow the user to add the pressure breaker or the pump information to the optimization. The coding should prepare easily not only the hydraulics table, which is the most important table for the high pressure network, but also cost and piezometric level tables. After deciding these standards, a flowchart (Algorithm) for the coding is created (Figure 3).

The code includes four worksheets which are named as: parameters, pipes, pressure breaker (Or pump), and network. Firstly, the user should enter the necessary information on the parameters worksheet. Then, if there is a need to make changes on the pipes worksheet it should be done next. The main duty of the user is on the network worksheet. "Clear" button makes the network worksheet ready to start a new project. The user should enter the network information from upstream to downstream. He should enter the main channel on the first column and to the next column he should input if there is a hydrant with "H" or if there is a branch with "Y". And for the same line the other inputs are: distance in kilometers, ground elevation in meters and the area in hectare if there is a hydrant in order. There is a sample network page on the excel file to help the user enter the data correctly. If there is a pressure breaker or pump it should be entered to the Pressure Breaker worksheet with the same format in the network page.

Users will be mainly work on the parameters and the network worksheets which are the most important pages of the code (Their samples can be seen in Figure 5). After the user enter parameters and network data correctly, he should click "Prepare Input Data" button. This process makes corections automatically and warn the user if there is any typo or missing data. Also, it assigns nodes to all hydrants and branches so the code will understand where nodal points are. Then by clicking the "Solve" button, flow calculation collaborates with Clement's method (Flexibility) and calculates flow for each nodal points. After this process, the code is ready to choose pipe diameter with the limits of velocity that are produced by the pipe manufacturers. While selecting the pipe diameter the program also calculates the static pressure. Because the pipe diameters are differing with the pipe pressure class. Finally, dynamic pressure calculation is done and the EPNO solves the whole pressurized irrigation system. Additionaly, user also able to get related tables as a summary of the calculations.

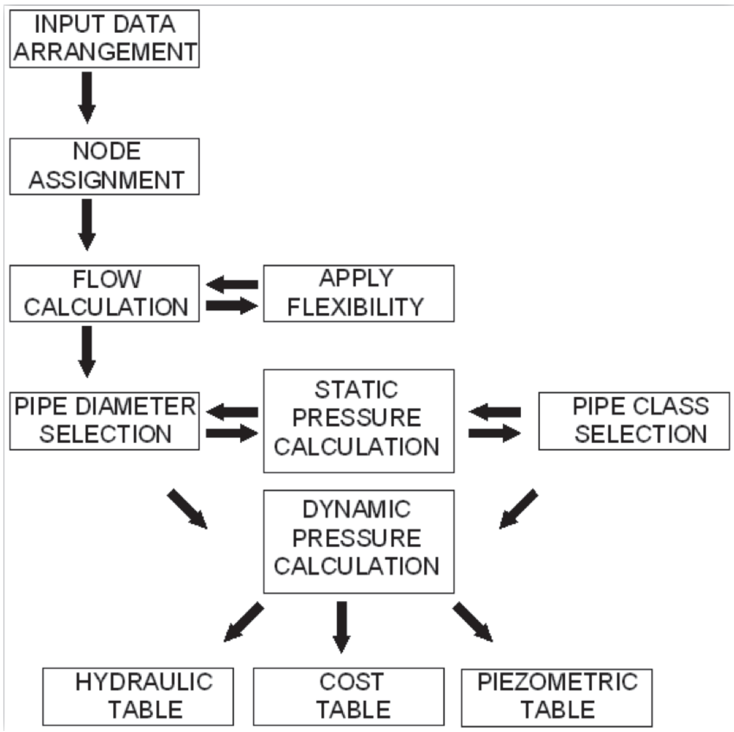


Figure 3. Flowchart for the irrigation network optimization by excel visual basic.

Study Area

Here is a small examplee of the medium pressure irrigation network project gained from DSI (The Republic of Turkey the General Directorate of State Hydraulic Works). It is solved by EPNO (Excel Pressurized Network Optimization). The irrigation area, in Tekirdag, Turkey, is shown in Figure 4. The reservoir is Lake Inanli, which is an artificial pond on the River Ulaz. There is a small agriculture area which is 56ha with an irrigation module q= 0.85 ls-1ha-1. Parameters of the Lake Inanli Irrigation Project are as follows:

- Maximum Head Elevation: 100m
- Minimum Head Elevation: 86m
- Head Loss: 1m
- Minimum Head Water Elevation: 85m
- Irrigation Module (q): 0.85 ls-1ha-1
- Irrigation Type: Medium Pressure
- Nominal Hydrant Discharge: 20 l/s
- Total Irrigation Area: 56 ha
- Net area Coefficient: 0.873
- Irrigation Operation Time: 20 hours

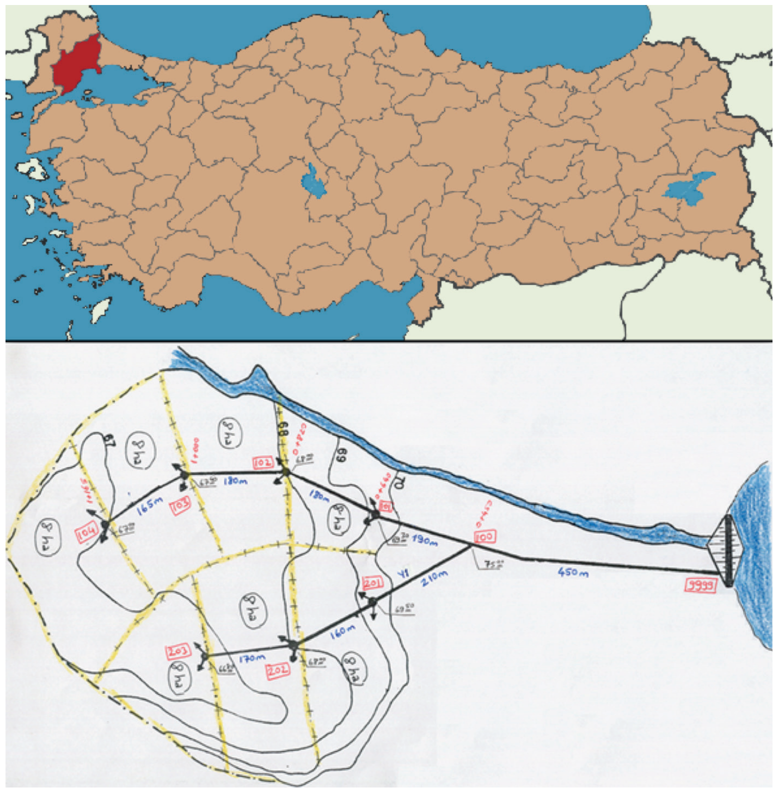
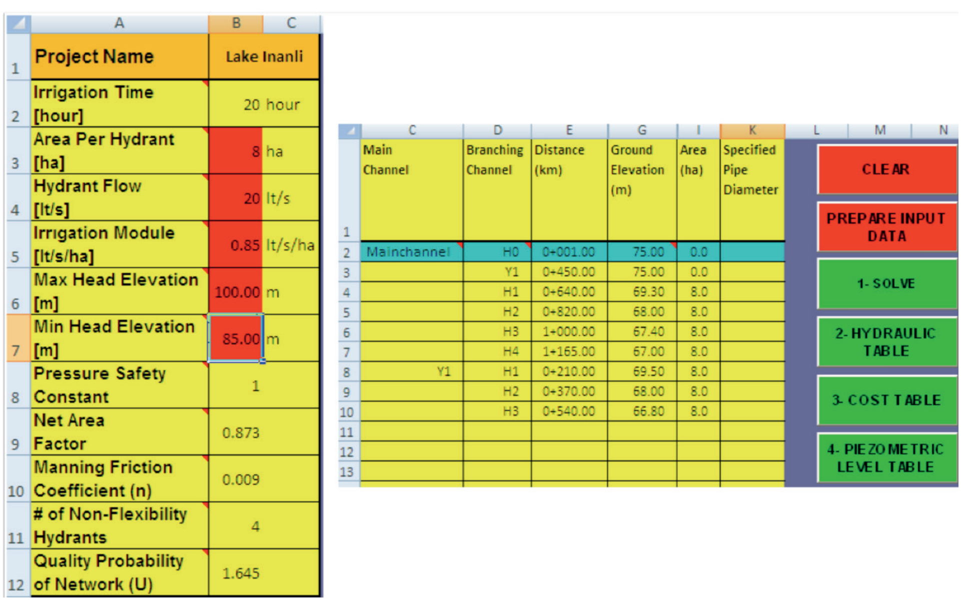


Figure 4. Location of the study area and Lake Inanlı irrigation project plan (DSI, 2009)



	A	B	C
1	Project Name	Lake Inanli	
2	Irrigation Time [hour]	20	hour
3	Area Per Hydrant [ha]	8	ha
4	Hydrant Flow [lt/s]	20	lt/s
5	Irrigation Module [lt/s/ha]	0.85	lt/s/ha
6	Max Head Elevation [m]	100.00	m
7	Min Head Elevation [m]	85.00	m
8	Pressure Safety Constant	1	
9	Net Area Factor	0.873	
10	Manning Friction Coefficient (n)	0.009	
11	# of Non-Flexibility Hydrants	4	
12	Quality Probability of Network (U)	1.645	

	C	D	E	G	I	K
1	Main Channel	Branching Channel	Distance (km)	Ground Elevation (m)	Area (ha)	Specified Pipe Diameter
2	Mainchannel	H0	0+001.00	75.00	0.0	
3		Y1	0+450.00	75.00	0.0	
4		H1	0+640.00	69.30	8.0	
5		H2	0+820.00	68.00	8.0	
6		H3	1+000.00	67.40	8.0	
7		H4	1+165.00	67.00	8.0	
8	Y1	H1	0+210.00	69.50	8.0	
9		H2	0+370.00	68.00	8.0	
10		H3	0+540.00	66.80	8.0	
11						
12						
13						

Figure 5. Parameters and network worksheets for the lake Inanli irrigation project.

Results and Discussion

A good irrigation network should be safe, affordable and ergonomic. Main purpose of the optimization process is to create a balanced pressurized irrigation network and a fair distribution. Therefore, high pressure at the upstream hydrant and low pressure at the downstream hydrant is not a good solution. All of the irrigation network's hydrants should have a balanced pressure. The pipe selection process is very important to make an affordable irrigation project since the pipe cost is the main cost in an irrigation project.

The Lake Inanlı Irrigation project is solved by the code. The output data from the NOP is also gained. Thus, the results from the EPNO and NOP are compared. Hydraulic table includes the computed irrigation hydraulics such as: flow, velocity, hydraulic gradient, static pressure, pipe's diameter, pipe's pressure class, dynamic pressure. The piezometric level comparison is in the Table 2 and in the Figure 6. The comparison of hydraulic tables is in the Table 3.

According to the results, EPNO gives output which is very close to the NOP's. Hydraulic table comparison shows very similar results however specially at the end of the lines, where the first method of Clément is not applied, EPNO calculates more discharge than the NOP. For instance, at the Hydraulic Table of Lake Inanli Irrigation, at the end of the lines the discharge from EPNO is 23 l/s although the discharge from the NOP is 20 l/s because EPNO chooses the higher value from the Clément's method and linear method at the end of the lines.

According to Figure 6, it is clear that the EPNO generates a pressurized irrigation network with a better balanced dynamic pressure distribution which is well for the irrigation systems. At the downstream hydrants there is higher dynamic pressure.

These differences are mainly because of the more detailed input of the pipe diameters. While modelling with the NO, user is not able to input inner and outer pipe diameter or thickness related with the pressure class. After the NO solves a system user changes the pipe diameter to the closest inner diameter in that pressure class. But this change doesnot have any effect on the velocity and so on the flow and pressure. However, some researchers say this effect is negligible, EPNO shows that, in big scale pressurized irrigation distrubiton systems, especially at the end of the lines there is a huge effect on the pressure that can result the pipe burst.

Table 2: Comparison of the piezometric level for the Lake Inanli irrigation project

LAKE INANLI PIEZOMETRIC LEVEL TABLE				
MAIN CHANNEL	**BRANCHING CHANNEL**	**KM**	**PIEZOMETRIC LEVEL (m)**	
			EPNO	**NOP**
MaincHannel	-	0+000	85.00	85.00
	Y1	0+450	81.36	81.97
	H1	0+640	80.18	80.99
	H2	0+820	79.03	79.24
	H3	1+000	77.36	76.21
	H4	1+165	76.10	74.80
Y1	-	0+000	81.36	81.97
	H1	0+210	80.02	79.93
	H2	0+370	78.53	77.67
	H3	0+540	77.23	75.71

*EPNO: Excel Pressurized Network Optimization *NOP: Network Optimization Program

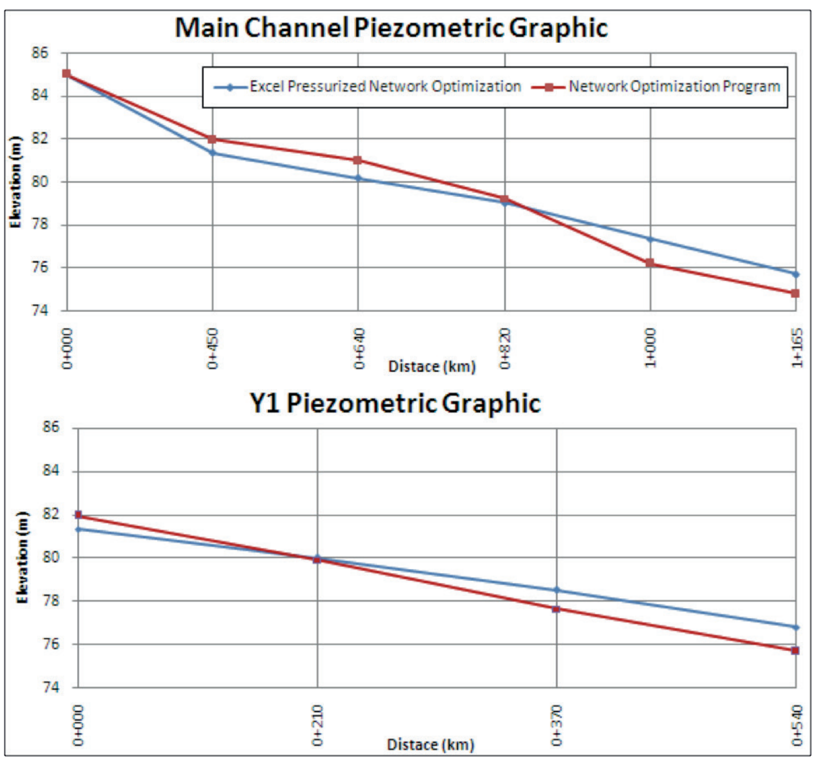


Figure 6. The Lake Inanli irrigation project, piezometric table comparison.

Table 3: Comparison of results from the code and the network optimization program

CHANNEL	BRUT AREA (ha)	FLOW Q (lt/s)	VELOCITY V (m/s)	HYDRAULIC GRADIENT J (m/m)	PIPE DIAMETER (mm)		PIPE LINE			HYDRANT					NOTES
					INNER	OUTER	MAXIMUM STATIC PRESSURE (m)	PRESSURE CLASS (atm)	TYPE	AREA (ha)	FLOW (lt/s)	NUMBER OF OUTLET	TYPE	MINIMUM DYNAMIC PRESSURE (m)	
Lake Inanli Hydraulic Table From EPNO (Irrigation Network Optimization Coded by Excel Visual Basic) $q=0.85\ ls^{-1}ha^{-1}$ and $n=0.009$															
M. Ch.	56.0	92	1.64	0.00810	266	280	27.0	4	PE100						Y1
	32.0	80	1.44	0.00618	266	280	30.7	4	PE100	8.0	20.0	2	D	10.88	H1
	24.0	60	1.35	0.00637	238	250	32.0	4	PE100	8.0	20.0	2	D	11.03	H2
	16.0	40	1.41	0.00932	190	200	32.6	4	PE100	8.0	20.0	2	D	9.96	H3
	8.0	23	1.26	0.01001	152	160	33.0	4	PE100	8.0	20.0	2	D	8.71	H4
Y1	24.0	60	1.35	0.00637	238	250	30.5	4	PE100	8.0	20.0	2	D	10.52	H1
	16.0	40	1.41	0.00932	190	200	32.0	4	PE100	8.0	20.0	2	D	10.53	H2
	8.0	23	1.26	0.01001	152	160	33.2	4	PE100	8.0	20.0	2	D	10.02	H3
Lake Inanli Hydraulic Table From The Network Irrigation Program by DSI $q=0.85\ ls^{-1}ha^{-1}$ and $n=0.009$															
M. Ch.	56.0	92	1.30	0.00674	300	315	27.0	4	PE100	-	-	-	-	-	Y1
	32.0	80	1.13	0.00513	300	315	30.7	4	“	8.0	20.0	2	D	11.70	H1
	24.0	60	1.35	0.00970	238	250	32.0	4	“	8.0	20.0	2	D	11.20	H2
	16.0	40	1.41	0.01411	190	200	32.6	4	“	8.0	20.0	2	D	9.30	H3
	8.0	20	1.10	0.01154	152	160	33.0	4	“	8.0	20.0	2	D	7.80	H4
Y1	24.0	60	1.35	0.00970	238	250	30.5	4	“	8.0	20.0	2	D	10.40	H1
	16.0	40	1.41	0.01411	190	200	32.0	4	“	8.0	20.0	2	D	9.70	H2
	8.0	20	1.10	0.01154	152	160	33.2	4	“	8.0	20.0	2	D	8.90	H3

Conclusions

Many researchers have been working on the water conservation because of the threat by the global warming on the existence of the water in the world. The agriculture, which is biggest consumer of the water, takes the biggest share on these studies. Many irrigation methods are developed to conserve the water depending on the agricultural area's properties. Among the irrigation methods, the best water saving technique is known as dripping and sprinkler systems that need to contact to a pressurized irrigation system.

Optimization and modeling of the pressurized irrigation system attracted many scientists. As a result, many irrigation optimization techniques are developed. The most used method is the first formula of Clément which use a probability technique. This method needs to be automated by computer programs since it is generally used for large scale irrigation projects. It can take many hours and days of calculations for large scale irrigation, however it looks an easy method. The existing computer program (NOP) is not very convenient due to limitation of the pipe size selection. In order to create a suitable computer program a coding is written on the Excel VBA. Results show that the first formula of Clément is a great method for pressurized irrigation network with an optimum discharge distribution and a balanced dynamic pressure.

The pressurized irrigation methods that are projected with the first formula of Clément should be monitored. The necessary confirmation should be studied if there is any. Since it is based on a probabilistic approach there could be some mistakes between the operation and the calculation. There are different irrigation routines in different cultures. So expectation of error is logical. So, these errors should also be monitored and they should be limited with some configurations.

The efficiency of the irrigation systems depends on not only the technological development but also educated farmers. However, there are many water saving irrigation techniques, the states should educate the farmers, especially in the developing countries. Traditional irrigation methods such as surface irrigation should be revised to pressurized irrigation methods.

Automation of the pressurized irrigation network is also possible. Development of the GPS (Global Positioning System) and wireless system allow the remote control, observing and maintenance of the irrigation network. There are many types of equipment that measure the amount of water in the soil. By using these equipments irrigation networks can be automated. Therefore, when the plant needs water the hydrant opens automatically, and the hydrant can be closed when the amount of water in the soil reaches a level.

References

Bruinsma, J. (2009). *How to Feed The World in 2050?* Paper presented at the FAO Expert Meeting, 24-26 June 2009, Rome.

Clément, R. (1966). *Calcul des débits dans les réseaux d'irrigation fonctionnant àla demande.* La Houille Blanche (5), 553-576.

The General Directorate of State Hydraulic Works . (2009). *General information for Irrigation Network Project* (pp. 53-75, 163-169). Antalya,: Turkey.

Feni, M., Khadra, R. & LaMaddalena, N. (2014). *Hydraulic and agronomic constraints of on demand pressurized irrigation networks optimization.* Geophysical Research Abstracts , Vol.16-6741. EGU General Assembly 2014, Vienna, Austria.

Labye, Y., Galand, A., Olson, M. & Tsiourtis, N. (1988). *Design and Optimization of Irrigation Distribution Networks.* FAO Irrigation and Drainage Papers, Vol. 44, Rome.

Onda, K., LoBuglio, J. & Bartram, J. (2012). Global Access to Safe Water: Accountig for Water Quality and the Resulting Impact on MDG Progress. *International Journal of Environmental Research and Public Health* 9 (3), 880-894.

LaMaddalena, N. (1997). *Integrated Simulation Modeling for Design and Performance Analysis of On-Demand Pressure Irrigation Systems.* Ph Instituto Superior de Agronomia.D. Dissertation, Lisboa: Universidade Technica de Lisboa. .

LaMaddalena, N. & Sagardoy, J. A. (2000). *Performance analysis of on-demand pressurized irrigation systems.* FAO Irrigation and Drainage Paper (59).

Shiklomanov, I. (1998). *World Water Resources: A New Appraisal and Assessment for the 21st Century.* (UNESCO, Ed.), Paris.:.

U.S. Bureau of Reclamation (1967). *Canals and Related Structures.* : United States Department of the Interior, Bureau of Reclamation Publication, Denver.

Extended Turkish Abstract
(Genişletilmiş Uzun Türkçe Özet)

Basınçlı Sulama Ağlarının Modellemesi ve Optimizasyonu

Tarımsal sulamanın başladığı zamanlardan günümüze kadar süregelen uygun ve verimli tarımsal sulama yöntemine ilişkin araştırmalar, birçok farklı sulama şebekesi yöntemi ve bu yöntemlere uygulanabilecek optimizasyon tekniklerinin ortaya çıkmasını sağlamıştır. Küresel ısınma ile birlikte birçok araştırmacı su tasarrufu üzerinde araştırmalar yapmaya başlamış, suyun korunumunu teşvik etmek için devletlerin destek vermesi üzerine özel sektör bu konulardaki çalışmalarına hız vermiştir. Tarım sektörü suyun en büyük tüketicisi olduğundan çalışmaların çoğu bu sektör üzerine yoğunlaşmıştır. 1970'li yıllarda ucuz ve etkin kullanılabilen plastik boruların keşfiyle birlikte su tasarrufu sağlayabilecek yöntemlerin geliştirilmesi hız kazanmıştır. İlerleyen yıllarda basınçlı tarımsal sulama yöntemlerinin geliştirilmesiyle yağmurlama sulama sistemleri tarım sektöründe kullanılmaya başlanmıştır. Suyu verimli ve tasarruflu bir şekilde kullanarak da sulama yapılabileceği görüldükten sonra birçok tarımsal sulama yöntemi ve buna bağlı olarak farklı optimizasyon teknikleri geliştirilmiştir.

Günümüzde optimizasyon teknikleri genellikle üç kategoriye ayrılır: Deneysel metodlar (US Bureau of Reclamation, 1967), istatistiksel metodlar (Clément, 1966) ve rastgele hidrant operasyonuna bağlı metodlar (Lamaddalena, 1997). En çok kullanılan optimizasyon yöntemlerinden biri olasılık hesaplarına dayanarak en uygun şebeke karakteristiklerini ortaya çıkaran Clément'in birinci yöntemidir. Bu yöntem büyük ölçekli sulama projeleri için uygulandığında genellikle daha iyi sonuç vermektedir.

Devlet Su İşleri'nin kullandığı "Network Optimizasyon Programı (NOP)" çok eskiden kodlanmış bir program olduğundan günümüzde ihtiyaçlara kısmen cevap vermekte fakat yetersiz kalmaktadır. Bu çalışmada, EXCEL VBA kodlama dili kullanılarak ve Excel tablolarından faydalanılarak bir yazılım programı üretilmiştir. Bu program ile 1. Clément yöntemi kullanılarak basınçlı sulama sistemlerinde su ihtiyacına göre akış dağılımı optimize edilebilmekte, boru içi akış hızı limitlerine göre boru çapları belirlenebilmekte ve düğüm noktalarındaki statik ve dinamik basınçlar hesaplanabilmektedir. Ayrıca piezometrik kotlar ve boru maliyet tablosuda kolayca oluşturulabilmektedir. Network Optimizasyon Programı ile bu çalışmanın çıktıları karşılaştırılmıştır. Böylece, girdi olarak kullanılan boru iç çapları gibi ufak detayların aslında sonuçlarda büyük farklar oluşturabileceği ortaya konulmuştur. Ayrıca, programın basınç ve debi açısından daha dengeli bir dağıtım yaptığı açıkça görülmektedir. Özellikle hat sonlarında daha yüksek basınç sağlayarak çifçilere daha eşit bir su iletimi sağlanabilmektedir.

Clément'in birinci methodu Olasılık yaklaşımı ile hesaplama yaptığı için model sonuçları ile uygulama sonuçları arasında belirli bir orana kadar uyumsuzluk olması muhtemeldir. Bu hataları en aza indirgemek için alışılagelmiş tarımsal geleneklerin bölgesel incelenerek gerekli parametrelerin doğru bir şekilde belirlenmesi çok önemlidir.

Basınçlı sulama şebekelerinin otomasyonu ve uzaktan kontrolü gelişmiş CBS (Coğrafi Bilgi Sistemi) donanımları, kablosuz iletişim araçları, uzaktan kontrol sistemleri ile mümkün olmaktadır. Toprak nemini ölçen cihazlardan faydalanarak bitkiye ihtiyacı olduğu kadar su otomatik vanaların kontrolü aracılığı ile verilebilir. Kısaca, bitki kök bölgelerindeki nemölçer ile su ihtiyacı olduğunda vanaya iletilen komut ile su iletilebilir ve su doygunluğuna ulaştığında vana kapatılarak ihtiyaç fazlası suyun drenaja gitmesi engellenebilir.