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An Optimization Model and Waterhammer for Sprinkler Irrigation Systems

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Abstract

There are many possible layouts for transporting water from its source to hydrants. That is why the most economical solution must be found. In practice, trial and error procedures are usually applied to determine the economical layout. The diameters of conveyance systems are then found by optimizing the network. However, such an approach does not guarantee an optimum solution. Nowadays, there are many models and related computer programs to solve this problem, but they also have many drawbacks. For example, dynamic programming procedures have limited usage due to the necessity of preparing new programs for each application.

In sprinkler irrigation systems, which are pressurized branched piping systems, flow changes initiate pressure fluctuations called "waterhammer". Such hydraulic transients must be investigated thoroughly for the safety of the system.

For the economical design of a sprinkler irrigation system for a given field, a two-step procedure comprising 1. optimization of system layout, 2. optimization of the system, may be used, but it is usually misleading to separate these two steps. This is because the diameters must be known to optimize the layout, and the layout of the system is necessary to determine the diameters. That is why these two steps must be handled together for the optimum design.

In this study, the shortest path algorithms of Graph theory are first used for determination of the layout and then the optimum diameters are determined. The economical solution is investigated by taking into account the cost of each pipe segment and by changing their lengths. The obtained networks are then optimized to arrive at the economical system.

The dynamic programming models for optimizing the gravitational or pumping systems with one source are presented. The branched systems may have any configuration. Furthermore, a computer program is developed to analyze waterhammer by the use of the characteristics method with interpolation. The approach used is demonstrated in the case of a simple system and the results are evaluated.

Key Words: Sprinkler Irrigation, Optimization Models, Dynamic Programming, Waterhammer.

Yağmurlama Sulama Sistemlerinin Eniyilenmesi ve Su Darbesi

Özet

Dünyada ve Türkiyede gittikçe daha büyük oranlarda kullanılmaya başlanan yağmurlama sulama sistemlerinin, projelendirme aşamasında ekonomik çözümlerinin aranması gerekmektedir. Kaynaktan alınan suyun hidrantlara iletilebilmesi için değişik güzergah ve çap seçenekleri bulunmaktadır. Bu seçeneklerden en ekonomik olanının bulunması gerekmektedir. Uygulamada, her ne kadar güzergahın belirlenmesi amacıyla bazı yöntemler geliştirilmiş olsa da, deneme - yanılma yöntemi ile en ekonomik güzergah belirlenmeye çalışılmakta ve belirlenen dal sistem şeklindeki güzergah üzerinde şebeke eniyilenerek çaplar belirlenmektedir. Şebekenin eniyilenmesi amacıyla günümüze kadar birçok programlama modelleri geliştirilmiştir. Bu modellerden, dinamik programlama modelleri üzerindeki çalışmalar, her örnek için ayrı bir model geliştirme zorunluluğundan dolayı sınırlı sayıdadır. Dal boru sistemi şeklindeki yağmurlama sulama sistemleri, basınçlı sistemlerdir ve sistemin herhangi bir noktasında oluşacak debi değişimleri, sistemde değişken akıma ve 'su darbesi' olarak adlandırılan, aşırı basınçların ortaya çıkmasına neden olabilmektedir. Su darbeleri, dal boru sistemleri için bir çok araştırmacı tarafından incelenmiş olmasına karşın, yağmurlama sulama şebekelerinde, uygulamada ya hiç gözönüne alınmamakta ya da güvenli tarafta kalacak şekilde kritik noktalarda kontrol yapılmaktadır.

Mevcut bir sulama alanı için yağmurlama sulama projesinin hazırlanması sırasında sistemin eniyilenmesi amacıyla, güzergahın eniyilenmesi ve şebekenin eniyilenmesi gibi 2 aşamada ekonomik çözüm aranabilmekte ise de, bu iki aşamayı birbirinden bağımsız olarak düşünmek mümkün değildir. Güzergahın eniyilenebilmesi için çapların bilinmesi gerekmektedir. Çaplar ise şebekenin eniyilenmesi sırasında belirlenmektedir. Bu nedenle bu iki aşamanın birbiriyle içiçe yürütülmesi gerekmektedir.

Bu çalışmada, öncelikle GRAPH teorisi en kısa yol algoritmalarından yararlanılarak, en kısa güzergah belirlenmektedir. Bu en kısa güzergah için şebeke eniyilenerek çaplar belirlenmekte, bu çaplara ait maliyet değerlerinden yararlanılarak, ekonomik güzergaha bir yaklaşım sağlanmaktadır. Elde edilen yeni güzergah üzerinde yeniden bir şebeke eniyilemesi yapılarak ekonomik sistem belirlenmektedir. Şebeke eniyilemesi amacıyla, tek kaynaklı, pompajlı veya yerçekimli dal şebekeleri eniyileyebilen dinamik programlama modelleri verilmekte, tek kaynaklı olmak koşulu ile her geometrideki dal şebekeleri eniyilebilecek şekilde geliştirilen bir bilgisayar programı tanıtılmaktadır. Yağmurlama sulama şebekelerinde oluşabilecek su darbeleri için ise, genellikle kullanılan sınır koşullarını içerecek şekilde, interpolasyonlu karakteristikler yönteminin kullanıldığı bir bilgisayar programı geliştirilmiştir. Geliştirilen bilgisayar programları kullanılarak, yağmurlama sulama sistemlerinin eniyilenmesine yönelik bir sayısal örnek çözülmüş ve sonuçlar verilmiştir.

Anahtar Sözcükler: Yağmurlama Sulaması, Eniyileme Modelleri, Dinamik Programlama, Su Darbesi.

1. Introduction

Water may be conducted from spring to plants by open channels or pipeline systems, and given to plants by surface sprinkler. Although it was thought that sprinkling irrigation will support the classical surface irrigation, it tends to replace the surface irrigation mainly in developed countries [12]. Sprinkler method is suitable for thin ground, too permeable ground and stiff ground which may be eroded by surface irrigation. Sprinkler irrigation may irrigate more ground than surface irrigation but sometimes the of energy requirement increases because of supplementary pumping.

As the efficiencies in classical and sprinkler irrigation systems are 0.50 and 0.70 respectively, when the sprinkler irrigation system is used water quantity required decreases by 40% or, with the same quantity of water irrigated land may be increased by 40%. The efficiency is much greater in the case of soils with high permeability.

In contrast to surface irrigation, when a sprinkler irrigation system is used, the field does not need any leveling. In regions where the water table is near the surface, the sprinkler irrigation system may be used without causing a notable change in the water table.

As drainage channels are not needed in sprinkler irrigation, larger areas may be irrigated than with classical irrigation methods.

2. The Optimization of the Layout of Sprinkler Irrigation Network

2.1. The Shortest Path

To determine the shortest path, many algorithms were developed in GRAPH theory [3,8,9]. These algorithms may be used to determine the shortest path from a spring to a target [3,4,8]. The basic concept of these algorithms is based on obtaining the shortest tree which has the shortest branches. Such a tree is called a 'SPANNING TREE' [8].

When a SOLLIN Algorithm is used, one starts by connecting the spring to the nearest node. This branch is connected with the nearest node to this branch and the obtained tree is connected with the nearest other node thus the drawing of tree is completed. Loops are not allowed.

2.2. Steiner Tree

It is possible to obtain trees that are shorter than Spanning trees. For example, in the case of three nodes A, B and C, there is a point M for which the sum MA+MB+MC is smaller than the sum of two segments AB+BC (Fig. 1). This point M is called the "Steiner point".

The angle between the segments MA, MB and MC is 120° [4]. When there are a lot of points in the network, the number of Steiner points increases which lead to difficulty in obtaining the Steiner tree. To get a Steiner point, at least three points are required. There are N-2 Steiner points for a system consisting of N nodes. If there are more than 3 points, more than one Steiner tree will exist. The shortest of these trees must be obtained. However, a general mathematical formulation of a Steiner tree has not been obtained yet. The benefit is at most 13.34% when the shortest tree is obtained [11]. In practice, instead of looking for the shortest tree, the increase in Steiner points may be sufficient.

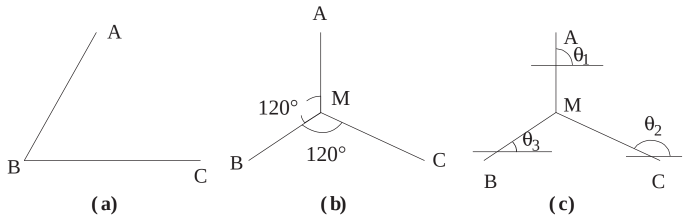

Figure 1. The shortest path in the case of 3 nodes

2.3. Determination of Steiner points

Position of Steiner points for groups, which have three, four and five nodes, may be obtained using transparent paper [4]. It may be determined easily if there are three nodes [11]. Moreover, the position of Steiner nodes for groups, which have 3, 4, and 5 nodes, may be obtained analytically. Slope of branches, which connect the Steiner point with A, B, C nodes, may be obtained as shown below:

$$\tan\theta_1 = \frac{y_M - y_A}{x_M - x_A};\ \tan\theta_1 = \frac{y_M - y_C}{x_M - x_C};$$
$$\tan\theta_1 = \frac{y_M - y_B}{x_M - x_B} \qquad (1)$$

As the angle between two successive branches is 120°, the following equations may be written:

$$\tan(\theta_1 - \theta_3) = \tan 60°;\ \tan(\theta_2 - \theta_1) = \tan 60°; \ (2)$$

Combining Equations (1) and (2), the following expressions are obtained:

$$\begin{aligned} &x_M^2 + y_M^2 - x_M(x_A + x_C - \frac{y_C - y_A}{\tan 60°}) - \\ &y_M(y_A + y_C - \frac{x_A - x_C}{\tan 60°}) + \\ &x_A x_C + y_A y_C + \frac{y_A x_C - y_C x_A}{\tan 60°} = 0 \end{aligned} \qquad (3)$$

$$\begin{aligned} &x_M^2 + y_M^2 - x_M(x_B + x_A - \frac{y_A - y_B}{\tan 60°}) - \\ &y_M(y_B + y_A - \frac{x_B - x_A}{\tan 60°}) + \\ &x_B x_A + y_B y_A + \frac{y_B x_A - y_A x_B}{\tan 60°} = 0 \end{aligned} \qquad (4)$$

Position of the Steiner node is obtained by the simultaneous solution of Equations (3) and (4).

If there are four nodes, coordinates of Steiner nodes M1 and M2 may be obtained from four nonlinear equations. However, in the case of five nodes, the Steiner points M1, M2, M3 may be determined from six nonlinear equations. As these obtained equations are nonlinear, they may be solved only by numerical algorithms [1].

2.4. Investigation of the Most Economical Path

The shortest path may be obtained as explained in Sections 2.1 and 2.2, but the shortest path is not always the most economical path since the cost depends not only on the length of the path but also onthe capacity and hence the diameter of branches.

Once the shortest path is obtained, the most economical solution may be obtained by moving Steiner nodes. For example in the case of 3 nodes, Steiner node M was translated into point M' as shown in Figure 2. As the diameter and consequently the cost of MA line get larger, the length of MA diminishes and their lengths increase, because of the small cost of MC and MB lines.

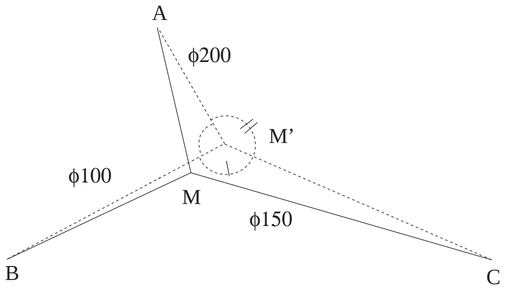

Figure 2. Passage from the shortest path to the most economical path in the case of three points

If C_1, C_2 and C_3 are the cost of lines MA, MB and MC, respectively,

$$C_1\vec{i} + C_2\vec{j} + C_3\vec{k} = 0 \quad (5)$$

may be written [4]. The angles between the branches connected at point M′ may be determined as shown in Figure 3.

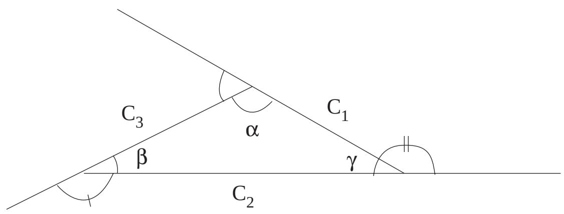

Figure 3. The angles of connected branches obtained from the costs.

From the cosinus theorem:

$$\cos\alpha = \frac{C_1^2 C_3^2 - C_2^2}{2C_1C_3};\ \cos\gamma = \frac{C_1^2 C_2^2 - C_3^3}{2C_1C_2} \quad (6)$$

The shortest path had been fixed, this path had been corrected by Steiner nodes, the pipe diameters are determined by the dynamic programming model explained in Section 3, later, positions of the Steiner point are translated.

As the angles between branches have been changed, Equations (2) written in the case of 3 points, become,

$$\tan(\theta_1 - \theta_3) = \tan\alpha = \frac{\sqrt{1-\cos^2\alpha}}{\cos\alpha} \quad (7)$$

$$\tan(\theta_2 - \theta_1) = \tan\gamma = \frac{\sqrt{1-\cos^2\gamma}}{\cos\gamma} \quad (8)$$

The new position of Steiner point may be found from Equations (7) and (8). Positions of Steiner points may be determined by defining the angles between branches in the case of 4 or 5 points.

3. Dynamic Programming Models

In sprinkler irrigation systems, the optimization of diameters includes the choice of diameters of each pipe [2]. In this study, dynamic programming models developed for gravitational or pumping system having branched pipes with one source are presented.

The junction points and deliveries are considered stage points and their piezometric heads are considered states. Decision variables are headlosses between two stages. Defining the diameter of the pipe that will correspond to this loss and its cost, the headloss that minimizes the total cost may be chosen. The objective function is the least cost of the system. Transfer function is defined as equations of headloss.

3.1. Dynamic programming models for gravitational systems

The hydraulic head at the upstream is a datum, and, one looks for the most economical diameters which satisfy the pressure and velocity criteria in gravitational systems. The objective function of the dynamic programming model for serially connected gravitational systems is expressed as follows:

$$\text{The least } M = \sum_{i=1}^{N}\sum_{j=l}^{K_i} r_{i,j}x_{i,j}Pd_{i,j} \quad (9)$$

where r_{ij} is the amortization factor of the j th pipe in the i th line [6], N is the number of the line, K_i is the number of pipes having different diameters in i th line, Pd_{ij} is the unit cost (TL/m), x_{ij} is the length of the j th pipe in the i th line (m), S_i is the number of stages upstream of the i th line, and if $k = S_i$. Recursive equations of this objective function are written as:

$$f_k(d_{k,j}) = \sum_{j=1}^{K_i} r_{i,j}Pd_{i,j}x_{i,j}$$

$$\text{for‘}i = 1\text{‘st state} \quad (10a)$$

$$f_k(d_{k,j}) = \sum_N \left[\sum_{j=1}^{K_i} r_{i,j} P d_{i,j} x_{i,j} + f_i(d_{i,j}) \right]$$

for‘$i = 2$‘st state (10b)

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$$f_N(d_{N,j}) = \sum_N \left[\sum_{j=1}^{K_i} r_{i,j} P d_{i,j} x_{i,j} + f_i(d_{i,j}) \right]$$

for‘$i = N - 1$‘th state($k = S_{N-1} = N$) (10c)

Boundary conditions of the model are:

1. The diameters cannot increase in the direction of flow.
2. The flow velocity must be between the minimum and maximum allowable values.
3. The pressure must be between the minimum and maximum allowable values.
4. The sum of the lengths of pipes having different diameters in a line must be equal to the length of this line.
5. The lengths of pipes having different diameters in a line must be positive or zero.
6. Piezometer level at the upstream (HN) is known.

These boundary conditions, the transfer function, and the objective function define the model.

The model is solved from the downstream direction to the upstream. The total cost at a stage represents the cost of the part of the branch placed at the downstream of this stage. If solved stage is a junction, this stage is on two branches and it represents the total cost of these branches.

To determine the relation between cost and diameter, a continuous function $M = a + bD^c$ or discrete values may be used. In this relation D is the diameter, a, b and c are coefficients. The computer program requires the numerical values of discrete variables.

3.2. Dynamic Programming Models for Pumping Systems

The dynamic head of the pump is a parameter that the designer chooses. The sum of energy cost and network cost must be minimum. Pumping systems may be in three different forms as shown in Figure 4.

In Figure 4a, the pump station supplies water to the network. In Figure 4b, the pump station supplies water to a reservoir on the ground. Figure 4c illustrates the case in which the pump station supplies water to an elevated tank.

In the first case (Figure 4.a), the objective function of a system with series pipes is:

$$\text{the least } M = \text{ the least} \left[\sum_{i=1}^{N} \sum_{j=1}^{K_i} r_{i,j} P d_{i,j} x_{i,j} + P_e H_p Q_n \right] \quad (11)$$

in which H_p is dynamic head of the pump (m), P_e is energy cost (TL/(m^3/s)/m/year), Q_n is water discharge (m^3/s). If k is equal to S_i, recursive equations are the same equations given for gravitational systems, except for the state $(N-1)$. The recursive equation corresponding to the $(N-1)$ th state is:

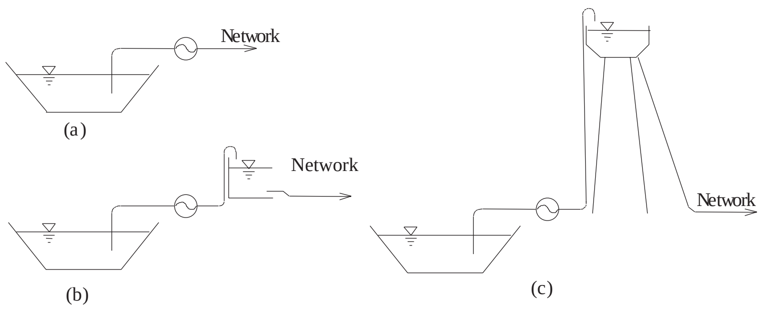

Figure 4. Pumping systems.

$$f_N(d_{N,j}) = \sum_N \left[\sum_{j=1}^{K_i} r_{i,j} P d_{i,j} x_{i,j} + f_i(d_{i,j}) \right] + P_e H_p Q_n \quad \text{for } 'i = N-1\text{'th state } (k = S_{N-1}N) \tag{12}$$

Boundary conditions are those given in the dynamic programming model for the gravitational system except the condition with upstream end head where the pumping cost must be included.

In the second case, where the pump supplies water to the reservoir on the ground as shown in Figure 4b; the place of the reservoir is chosen according to the topographic conditions and the water level is known. That is why the cost of energy and the cost of network are analyzed separately.

In the third case, (Figure 4c) the cost of the network and the cost of energy depend on the water level in the reservoir. The total cost must include the cost of the elevated tank. The objective function is written as:

$$f_N(d_{N,j}) = \sum_N \left[\sum_{j=1}^{K_i} r_{i,j} P d_{i,j} x_{i,j} + f_i(d_{i,j}) \right] + P_e H_p Q_n + P_h H_h \tag{13}$$

where, H_h is the height of the elevated tank (m), P_h is its cost (TL/m). Usually, the cost of the reservoir for a given volume is expressed as a linear function of its height [4].

3.3. Waterhammer Analysis

Usually, the operating regime does not change with time, i.e., there is a steady flow. However, when the valve is closed or opened and when the pump starts up or stops, unsteady flows occur. Excessive pressures (waterhammer) develop which may damage the system [5]. Cavitations due to low pressure may also occur.

The waterhammer phenomenon is defined by the following momentum and continuity equations.

$$g\frac{\partial H}{\partial x} + V\frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} + \frac{fV|V|}{2D} = 0 \tag{14}$$

$$\frac{\partial H}{\partial x} + V\frac{\partial V}{\partial x} + \frac{a^2 \partial V}{g \partial t} + V \sin\alpha = 0 \tag{15}$$

where x is the distance, t is the time, $V(x,t)$ and $H(x,t)$ are the flow velocity and the piezometric head at point x and at time t, respectively, D is the diameter, f is the friction factor of the pipe, g is the gravitational acceleration, α is the pipe angle with the horizontal, and a is the pressure wave velocity.

These equations are hyperbolic partial differential equations. They cannot be integrated but may be solved by numerical methods, such as the characteristics method with the finite differences technique [13]. In the characteristics method with interpolation using the notations given in Figure 5, the equations in terms of the discharge Q become:

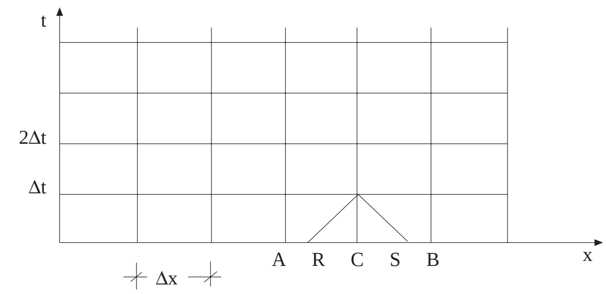

Figure 5. Notations used in the characteristics method with interpolations

$$C^+ : x_P - x_R = \left(\frac{x_R}{F} + a_R\right)(t_P - t_R) \tag{16}$$

$$K^+ : H_P - H_R + \frac{a_R}{gF}(Q_P - Q_R) - \frac{Q_R(t_P - t_R)}{F}\sin\alpha + \frac{a_R f Q_R|Q_R|}{2gDF^2}(t_P - t_R) = 0 \tag{17}$$

$$C^- : x_P - x_S = \left(\frac{Q_S}{F} + a_S\right)(t_P - t_S) \tag{18}$$

$$K^- : H_P - H_S - \frac{a_S}{gF}(Q_P - Q_S) - \frac{Q_S(t_P - t_S)}{F}\sin\alpha + \frac{a_S f Q_S|Q_S|}{2gDF^2}(t_P - t_S) = 0 \tag{19}$$

where F is the cross-sectional area and Q is discharge [5,7,13]. In Equations (16) through (19), x_p, t_p, H_p and Q_p are unknowns. Values at points R and S are calculated from known values at points A, B and C by interpolation [13].

The unknown values at an intermediate point are calculated by $K+$ and $K-$ equations which are valid on the $C+$ and $C-$ characteristic curves. But at the upstream end only the $K-$ equation and at the downstream end only the $K+$ equation may be written. That is why to determine two unknowns a second equation is needed, which is obtained from the boundary condition.

Waterhammer is a phenomenon which occurs when the flow rate changes. To determine the pressure surges, waterhammer, the dimensions of the system must be determined. As one obtains the dimensions after the optimization, it is not possible to compute waterhammer exactly. Approximate results given by ALLIEVI and MICHAUD equations may be used [10]. The pressure surges in the pipe can be calculated by the Michaud equation:

$$dH = \frac{2LV}{gT} \tag{20}$$

where, dH is the pressure surge (m), V is the velocity (m/s), g is the gravitational acceleration (m/s^2), T is the opening or closing time of valve (s) and L is the length of pipe (m). The pipe pressure should not exceed the allowable pipe pressure P_{adm}, and must be greater than the vapor pressure, P_{vap}

$$P_{adm} \geq H_i - Z_i + dH \tag{21}$$

$$P_{vap} < H_i - Z_i - dH \tag{22}$$

where H_i is the pressure head (m), and Z_i is the geometrical head (m).

4. Computer Programs

4.1. Optimization of the layout

The computer program named YSGOPT, with the flowchart given Figure 6, is developed in order to optimize the layout. It has two parts. The shortest path is determined in the first part and this path is improved by STEINER notes to obtain then the economical layout.

First, the shortest path is determined by the SOLLIN algorithm and is drawn on the screen. However, some unsuitable results may be obtained in terms of hydraulics. Then some lines may be omitted and some new lines may be added by the user. Later, the number of points are entered using the keyboard and the changed layout may be seen on the screen. Number of the nodes, which will be connected, can be 3, 4 or 5. After that the network is optimized and the most economical diameters for the network are determined using the program YSSOPT explained in 5.2.

In the second part according to unit cost, the positions of Steiner points are changed to get the most economical solution. The diameters must be checked by YSSOPT, to optimize the network.

4.2. Optimization of the network

The YSSOPT computer program, with the flowchart given in Figure 7, developed to optimize the network, is based on the dynamic programming approach. It may optimize all networks having one source. First, standard pipe diameters, energy losses and maximum and minimum piezometric levels at nodes are determined. They depend on maximum and minimum velocity values. Then the diameters are determined. If it is a pumping system, energy and initial investment costs are optimized. If the system is a gravitational system, only initial investment costs are optimized. Pipe diameters and pump dynamic head are determined. Computation is started from the downstream (I=1). The execution time for the numerical example given in Section 6, is about 10 seconds.

4.3. Waterhammer

The YSSUDAR computer program whose flow chart is given Figure 8, is developed in order to compute waterhammer in the sprinkler irrigation systems by the characteristics method with interpolations. The execution time for the numerical example given in Section 6, is about 20 seconds.

A reservoir, a pump or a surge chamber define the boundary conditions at the upstream. Diameter changes, branch, a reservoir, dead end, valve at the end of the line, valve in the line, two-phase flow, pump, the surge chamber on the middle of the line, one-way tank, surge tank, valve in the interior of a line, check valve, air valve, surge suppressor define the boundary conditions at the downstream.

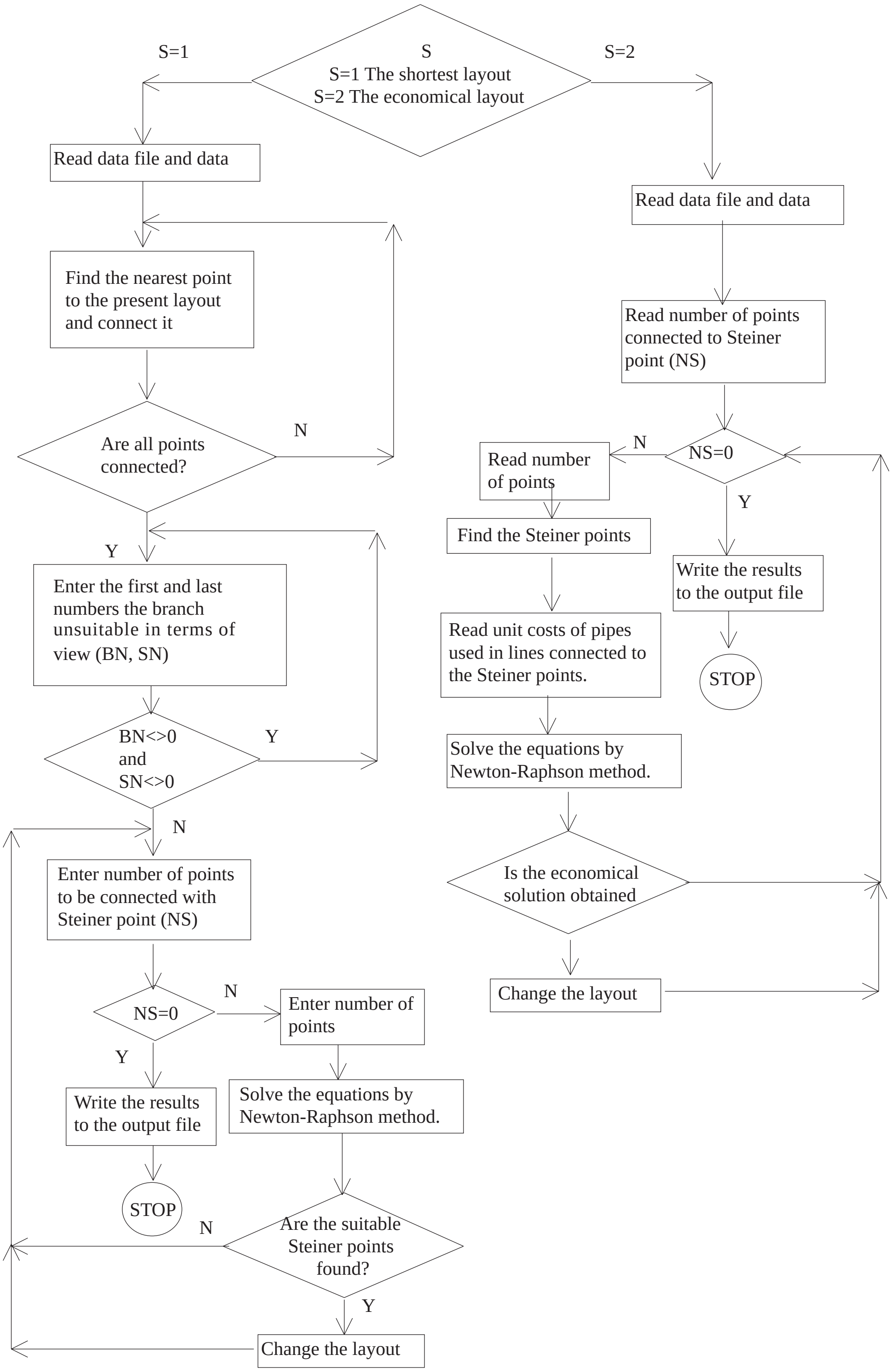

Figure 6. Flowchart of YSGOPT computer program

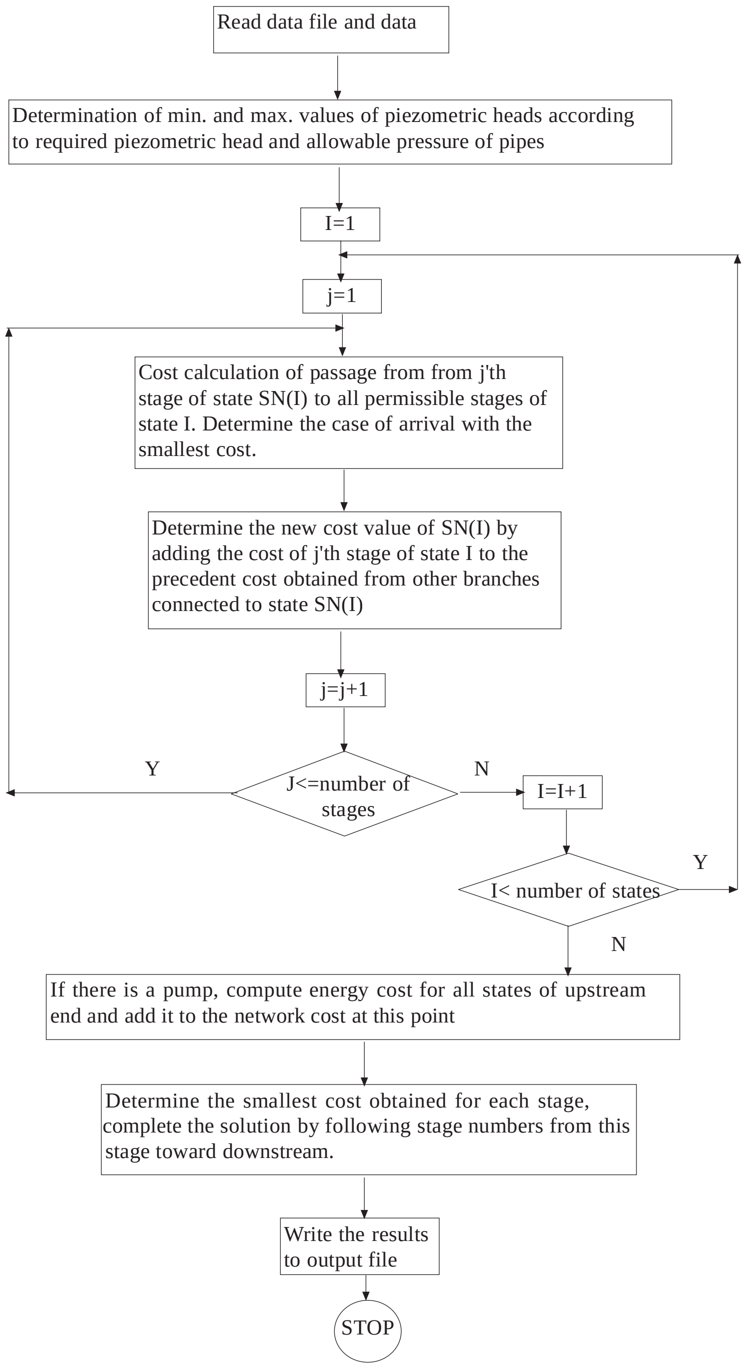

Figure 7. Flowchart of YSSOPT computer program

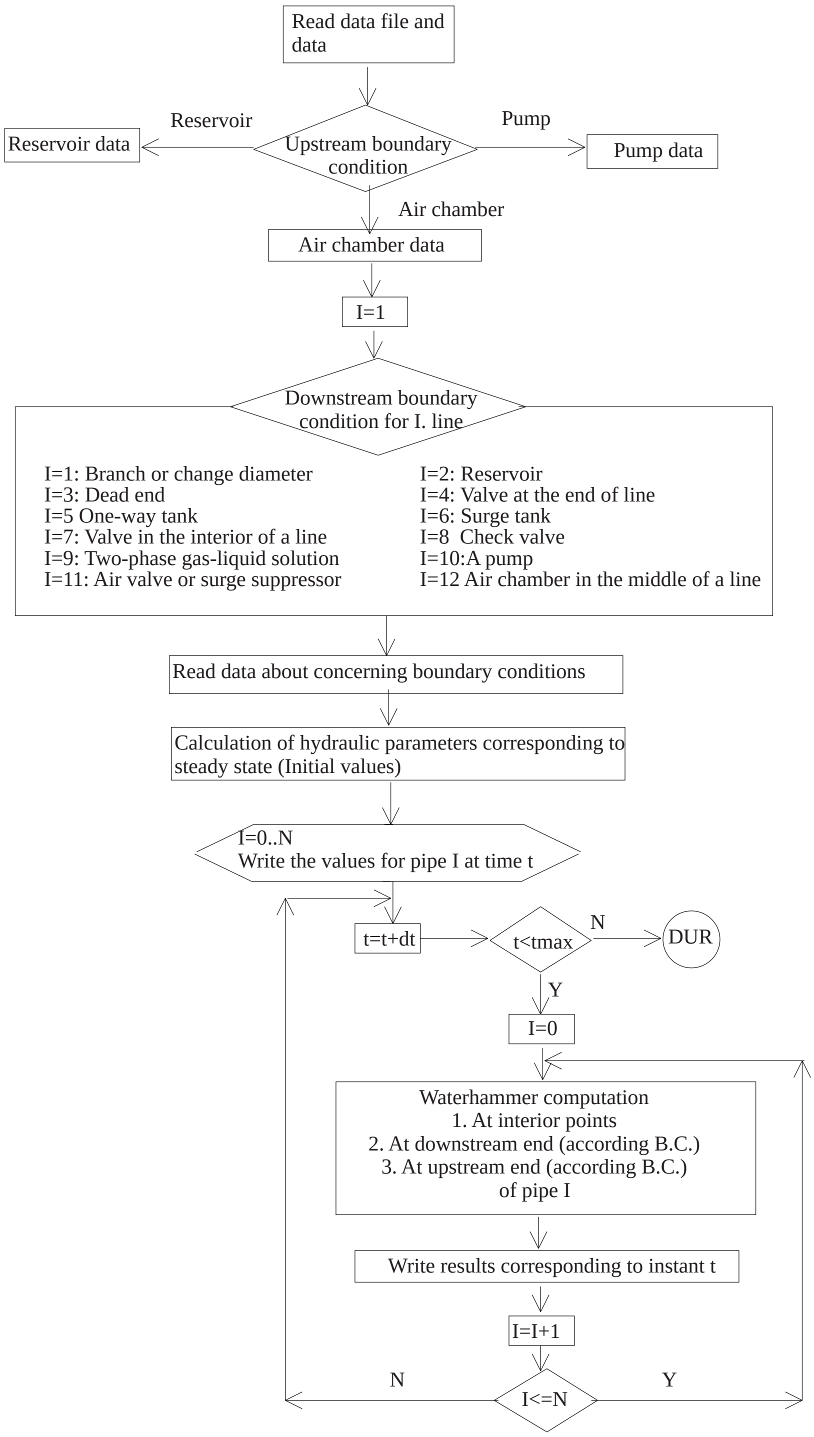

Figure 8. Flowchart of YSSUDAR computer program

5. Numerical Example

Before designing a system, the necessary water quantity must be determined. This quantity depends on plant species, ground species and parcel dimensions. After optimization of layout and network, waterhammer effects are computed and safety of network is controlled.

The numerical example is a system that has only one source. This numerical example is extracted from CLEMENT and GALAND [4]. The coordinates of source and nodes must be known for the layout optimization. Data of hydrants are given in Table 1. The shortest path is determined by the YSGOPT program (Fig. 9). Then, a STEINER tree is searched by suitable Steiner nodes to shorten the layout (Fig. 10).

The positions of the STEINER nodes are changed to get a more economical layout by shortening the length of large-diameter pipes and increasing the length of small-diameter pipes. The unit costs are considered in this computation. The diameters are determined by the YSSOPT computer program. The new layout obtained from the YSGOPT program is shown in Figure 11. The actual layout is shown in Figure 12 [4].

Optimization of the network is made by the YSSOPT computer program and the results are summarized in Table 2.

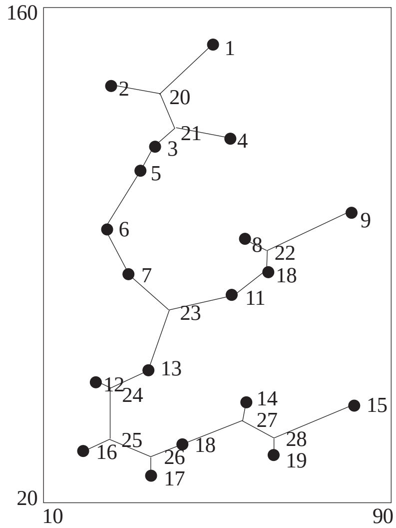

Figure 10. Numerical example, Shortened layout determined by Sollin algorithm by Steiner nodes

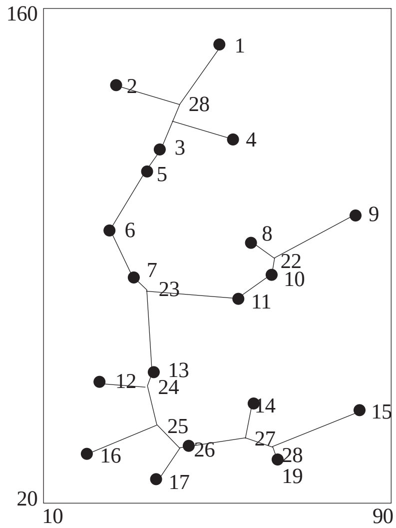

Figure 11. Numerical example, economical layout

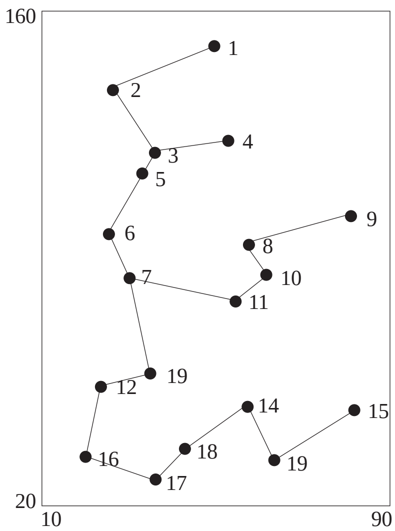

Figure 9. Numerical example, the shortest layout

Waterhammer effects were not considered in the study of CLEMENT and GALAND [4]. Valves, whose positions are shown in Figure 12, are assumed to be closed at different times in the system. The closure law of valves is given in Figure 13. Waterhammer computation results are given in Figure 14. The first solution corresponds to the closure of the valve at the 31st node by assuming that only areas placed in the left part are irrigated. The second solution corresponds to the closure of valve 14. The third solution is obtained by assuming that only areas placed in the right part are irrigated when valve

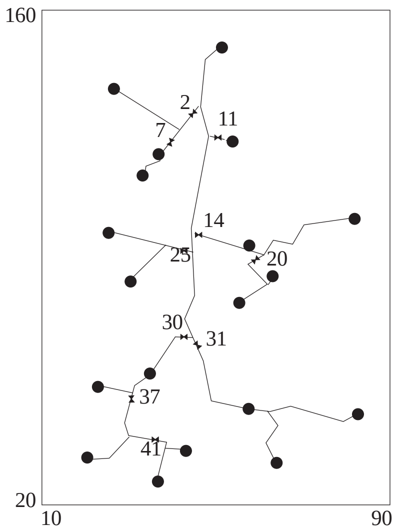

Figure 12. Numerical example, applied layout on the ground and valve positions plan

Table 1. Data of numerical example

Hydrant Number		Q (lt/s)	Coordinates(m) x	Y
(9000)	1	—	50	150
(103)	2	8.4	26	138
(102)	3	19.5	36	120
(101)	4	19.5	53	123
(104)	5	8.4	33	114
(105)	6	19.5	25	97
(106)	7	19.5	30	84
(109)	8	13.9	57	94
(110)	9	22.3	81	102
(108)	10	13.9	62	85
(107)	11	34.8	54	78
(112)	12	25	23	54
(111)	13	77.8	35	57
(116)	14	68.2	57	48
(118)	15	34.8	82	47
(113)	16	13.9	20	34
(114)	17	25	36	27
(115)	18	13.9	43	36
(117)	19	13.9	63	33

2 is closed. The fourth solution is about waterhammer caused by closure of valve 30. H_{max} and H_{min} represent the highest and the lowest pressures, respectively. T_{max} and T_{min} are the times when these extreme values occur. When the valves placed at the midpoint are moved, the high pressures occur at the upstream part, while the low pressures occur at the downstream part. As there is no a restrictive pressure condition in the computer program, some values below -10m are observed. The computations are repeated by placing air inlet valves at these points which open when the pressure value reaches -5m.

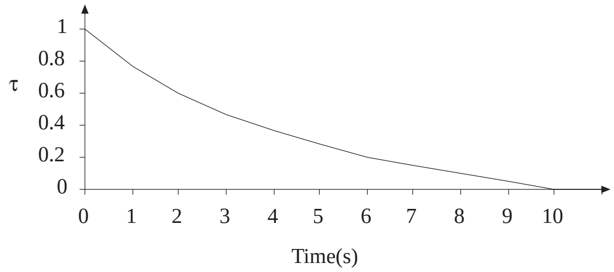

Figure 13. Closure law of valves.

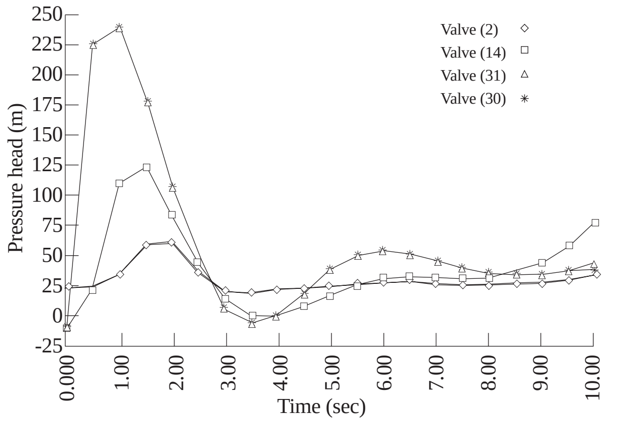

Figure 14. Waterhammer computation results for numerical example

6. Conclusion

This study may be considered to constitute three parts: The first part is about the optimization of the layout. The second one concerns the optimization of the network and the last part is about waterhammer analysis.

When the layout is optimized, in the numerical example, Clement and Galand sought the shortest layout with the use of Sollin algorithm and Steiner points for groups having 3, 4 and 5 points. They used a drawing method with transparent paper to get Steiner points. When the layout of water distribution systems is optimized, instead of the shortest path algorithms, the use of new methods taking into account the cost of each pipe seems to be much more accurate.

Table 2. Pipe lengths calculated by CLEMENT-GALAND and optimized lengths by YSGOPT

Diameter (mm)	Unit Cost (FF/m)	Pipe length (m)	
		CLEMENT-GALAND	YSGOPT & YSSOPT
100	112	685	685
125	130	535	533
150	145	1673	1680
200	195	1550	1537
250	240	1013	1057
300	285	1704	1668
350	400	0	
400	470	515	515
Total	cost (FF)	1661919	1660435

To date several optimization models for optimization of network have been developed. But dynamic programming requires a different model for each example. That is why the studies in this domain are very limited. In this study a dynamic programming model to optimize the sprinkler irrigation systems with one source is presented. The systems may be gravitational or pumping systems. If the nodes are correctly numbered any other networks can be optimized. It is possible to develop a general dynamic programming model in the similar way. This subject is worth investigating. The agreement between obtained results and those obtained by Clment and Galand is very good.

In the waterhammer computations, the characteristics method with interpolation is used to get more accurate results in the waterhammer analysis. The pressure surges may be controlled using a suitable control device.

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