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ORIGINAL ARTICLE

Integrated approach for the optimal design of pipeline networks

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Abstract This paper presents the development of a GIS-based model for water pipeline network data integration and analysis named Integrated Water Distribution network design and Calibration Utility (IWDCU). IWDCU tackles two main applications in the field of Water Distribution Network (WDN). The first application (ELGTnet) addresses hydraulic analysis for both looped and branched networks. Also, based on Evolutionary Algorithms (EAs), EAnet is a computer-based technique for the optimal hydraulic design of WDN that satisfies both design demands and pressures at all network nodes with lowest possible cost. For the abovementioned two computer applications, mathematical modeling was combined with Geographic Information System (GIS) application for better data visualization and for best performance. The application of this integrated approach was subsequently further tested in Kostol Irrigational area to evaluate its applicability to real applications and its performances in finding best commercial design of network.

1. IWDCU architecture

The architecture of the IWDCU tool is lightweight and open. It integrates three software components, as shown in the data flow diagram in Fig. 1.

Data from water utility are gathered and then exported to Microsoft Excel™ workbooks, accompanied by metadata. WDN hydraulic Modeling is performed with ELGTnet model based on "Extended Linear Graph Theory Model" presented by Gupta and Prasad 2000 and modified by Ayman 2010. Information is consolidated and then an application was made to find the optimal design of the network that satisfies all demands and pressures by means of EAnet. With this application, the ability to identify various types of Evolutionary algorithms options is available. Data are then extracted and converted into GIS format for visualization in the GIS data viewer ArcGIS 9.2 (ESRI, Redlands, CA). Results are then extracted and converted into GIS format for visualization and further querying.

2. ELGTNET

Water Distribution Network (WDN) represents a major portion of the investment in urban infrastructure and is consid-

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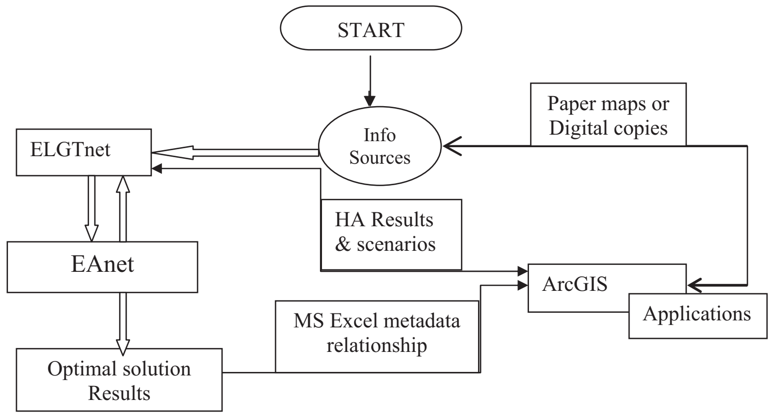

Figure 1 Data flow diagram for IWDCU GIS-based integrated tool for WDN.

ered a critical component of public works. The goal is to design water distribution systems to deliver drinking water for all areas satisfying design demands and pressure.

Pipe network analysis involves the process seeking the determination of discharge and associated pressure at every node. The analysis of a pipe network can be one of the more complex mathematical problems that engineers are called upon to solve. The proposed method uses (ELGT) presented by Gupta and Prasad [1] to formulate the model. This technique is modified to: (i) include new network components such as flow control valves, tanks, and for extended period simulation (EPS), and (ii) improve the convergence rate by introducing a modified method for the calculation of updated flows (Ayad [3]).

The proposed method is applicable if flow rates, heads, or a combination of both is specified at nodes in the network.

The method is applicable to hydraulic components that are commonly found in most distribution networks, such as pumps, valves, and junctions. An additional branch in the linear graph simulates pump and pressure reducing valve (PRV), respectively and the components and their graph models are given in Table 1. The head loss in a valve, fitting, or junction is approximated by its equivalent length, or by writing the head Loss equation in linear form and adding it to the head loss expressions that correspond to the pipes or branches connected to it. The method can be used for pipe failure analysis where the heads at nodes are not limited to specified values. To perform this analysis, entries corresponding to the pipe in question are set to zero in the matrix **S**.

2.1. Solution steps

1. Assume any initial flow rate $q0$ in the pipes (same in all pipes).
2. Calculate a stiffness factor($k = 1/r|q_0^{\propto -1}|$) for each pipe. (1)
3. Obtain the matrix **K** using $[\mathbf{K}] = [S]^T[k][S]$ (2)
4. Compute the unknowns(nodal heads and/or nodal flows)
   $$[K]_{n\times n} = [S]^T[k][S] \quad (3)$$
5. Compute pipe head losses using $[K]_{n\times n}[h_t] = -[I][q_t]$ (4)
6. Compute pipe flows using $[h_c] = [-S] \times [h_t]$ (5)
7. Compute the weighted flow rates in pipes using Eq. (6) with $b = 0.45$.
   $$q_i = \lambda h_i^{\alpha},\ \text{and}\ h_i = \left(\frac{q_i}{\lambda}\right)^{\frac{1}{\alpha}} \quad (6)$$
   where
   q_i = flow through pipe i.
8. Repeat steps 2–8, with the weighted flow rates calculated in Step 7, until the desired accuracy is achieved.

The solution algorithm incorporates an exact mass balance at each node. A negligible change in pipe flows after a succession of iterations indicates that the mass balance requirements have been met, and the solution has converged. The relative error, defined below, is considered to be a convergence:

$$\text{Criterion}\ \left(\frac{\sum_{i=1}^{P}|q_{cij} - q_{cij-1}|}{\sum_{i=1}^{P}|q_{cij}|}\right) < 0.1\% \quad (7)$$

where q_{cij} flow through pipe i in iteration j; q_{cij-1} flow through pipe i in iteration $(j-1)$.

2.2. EPAnet program

EPAnet is a public-domain, water-distribution-system modeling package developed by the U.S. Environmental Protection Agency's Water Supply and Water Resources Division. EPAnet performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPAnet tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps.

EPAnet first appeared in 1993 (Rossman [4]). The program can be downloaded from the World Wide Web. EPAnet is used as calibrating software to compare the performance of presented model named (ELGTnet). Also, the result of each model is being checked to ensure model accuracy.

2.3. ELGTNET applications

The model is used for the hydraulic simulation of a water distribution network. The presented model has been coded in

Table 1 Components characteristic for pipe networks.

Component	Symbol	Graph model	Test condition	Terminal equation	Stiffness (k)
Reservoir	hr	#X #a		$h_{it} = -h_t$	
Constant discharge pump	q #a	#X #a		$q_t = -q$	
Consumption	#a q	#X #a		$q_t = q$	
Pipe	#a #b	#a i #b		$h_i = r_i \times q_i^{1.852}$	$\frac{1}{r_i q_i^{0.852}}$
Booster pump	#a P #b	#a i #b #X	$q_o > q_p > 0$	$q_p = q_o - q_i \; q_i = \lambda h_i^{\alpha}$	* $\lambda^{\frac{1}{\alpha}} \times q_i^{\frac{\alpha-1}{\alpha}}$
Check valve	#a #b	#a i #b	$h_a > h_b$	$h_i = r_i \times q_i^{1.852}$	$\frac{1}{r_i q_i^{0.852}}$
Check valve (operative)		#a i #b	$h_a < h_b$	$q_i = 0$	0
PRV (operative)	#a #e #b	#a #e #b #X	$h_e > H_{set} \; h_b < h_a$	$h_i = h_a - h_e \; h_e = H_{set}$	$\frac{q}{h_a - h_e}$
PRV (inoperative)	#a #b	#a i #b	$h_b < h_a \; h_e < H_{set}$	$h_i = r_i \times q_i^{1.852}$	$\frac{1}{r_i q_i^{0.852}}$
PRV (reverse flow)	#a #b	#a i #b	$h_b > h_a$	$q_i = 0$	0
PRV (By pass reverse flow)	#a #b	#a i #b	$h_b < h_a \; h_b > H_{set}$	$q_i = 0$	0
FCV (operative)**	#a #e #b	#a #e #b #X	$h_a - h_b > h_x^*$	$h_i = h_x^* \; h_x^* = Q_{set}^{1.862} \times r_i$	$\frac{q}{h_x^*}$
FCV (inoperative)	#a #b	#a i #b	$h_a - h_b < h_x^*$	$h_i = r_i \times q_i^{1.852}$	$\frac{1}{r_i q_i^{0.852}}$
FCV (reverse flow)	#a #b	#a i #b	$h_b > h_a$	$q_i = 0$	0

Matlab® language (Release14) and applied on PC. Four networks are chosen to test the efficiency of the presented model, and a comparison between model results and EPAnet software [4]. Results show that the applied model named (ELGTnet) solves the different networks in less computational time, and iterations.

2.3.1. Florida water distribution network

Consider the Florida water distribution network as shown in Fig. 2. The Network consists of one tank, one pump, forty pipes and thirty-six junctions. Hazen William's roughness coefficient (C) is 100. The network can be found at EPAnet examples.

Table 2 summarizes results obtained from both EPAnet and ELGTnet models: the relative errors, number or iterations, and time to solve the network used by the two models. Table 2 shows that the results obtained from ELGTnet are closely identical to those obtained by EPAnet.

The above table shows that although the presented model (ELGTnet) had a relatively high relative error at first iteration, yet the network was solved in only four iterations, and in less computational time than EPAnet.

3. EANET

EAs computing techniques have been used for economical studies that concern water distribution networks, such as, economical design of pipe network, parallel expansion, and pipe rehabilitation and maintenance. EAs are used because of capability of searching vast and complex search space and locating near global optimal solutions rapidly the model created under the name "EAnet" combines either GA or SCE-UA models with either ELGTnet as hydraulic analysis models to obtain optimal design of water pipe network. Introducing a new adaptive penalty function the presented model has been coded

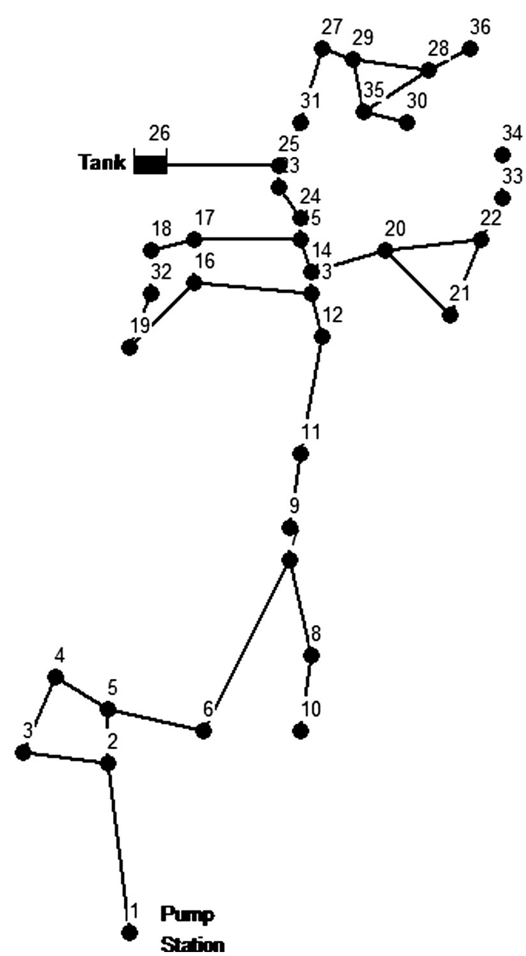

Figure 2 Florida water distribution network.

Table 2 Florida network EPAnet & ELGTnet results comparison.

Florida network	EPAnet	ELGTnet
Time (s)	0.796	0.18
No of iterations	7	4
T1	0.931972	86.3886
T2	0.042347	0.0564
T3	0.010643	0.0073
T4	0.00213	1×10^{-4}
T5	0.0009	
T6	1.6×10^{-3}	
T7	7×10^{-4}	
Max H diff (m)	0.00597	
Max Q diff (L/s)	9×10^{-4}	

in Matlab® language (Release14) and applied on PC (Ayman [2]).

3.1. EA-NET model formulation

The model created under the name "EAnet" combines either GA (Wang [5]) or SCE-UA (Duan et al. [6]) models with either ELGT-NET or EPAnet as hydraulic analysis models to obtain optimal design of water pipe networks.

3.1.1. MODEL options

The model I created has many options regarding both GA and SCEUA such as **Crossover** function: the model possesses 8 different crossover options (see Table 3).

To explain the 8 crossover options we start with Single point crossover as explained in Fig. 3.

EAnet chooses a random integer n between 1 and number of variables and then selects vector entries numbered less than or equal to *n* from the first parent, and selects vector entries numbered greater than n from the second parent.

Two point crossover is shown in Fig. 4.

EAnet chooses two random integers m and n between 1 and number of variables and then Selects Vector entries numbered less than or equal to m from the first parent, select vector entries numbered from $m + 1$ to n, inclusive, from the second parent, and vector entries numbered greater than n from the first parent.

Scattered crossover is shown in Fig. 5.

EAnet creates a random binary vector and selects the genes where the vector is a 1 from the first parent, and the genes where the vector is a 0 from the second parent, and combines the genes to form the child.

Table 3 Crossover options in EAnet.

Type of data	Method
ALL	Single point cross over
ALL	Two point cross over
ALL	Scattered crossover
Real	Intermediate crossover
Real	Heuristic crossover
Real	Arithmetic crossover
Real	One child staggered crossover
Real	Two child staggered crossover

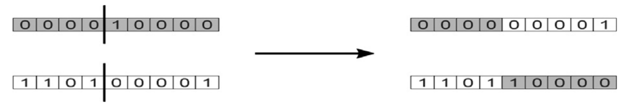

Figure 3 Single point crossover.

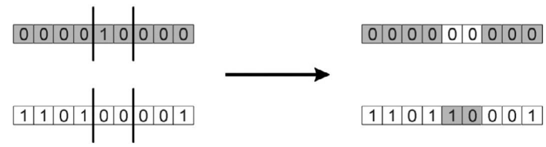

Figure 4 Two point crossover.

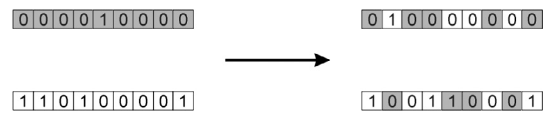

Figure 5 Scattered crossover.

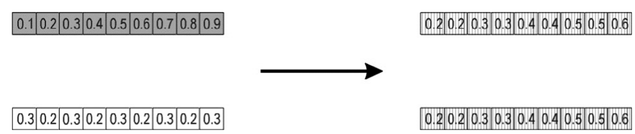

Figure 6 Arithmetic crossover.

Arithmetic crossover is shown in Fig. 6.

Arithmetic crossover is valid only for real representation coding, where EAnet creates children that are the weighted arithmetic mean of two parents. Children are always feasible with respect to linear constraints and bounds.

Intermediate crossover creates children by taking a weighted average (Ratio) of the parents. Eq. (8) explains the principle of intermediate crossover:

$$\text{Child} = \text{parent }1 + \text{rand} * \text{Ratio} * (\text{parent }2 - \text{parent }1) \quad (8)$$

Heuristic crossover returns a child that lies on the line containing the two parents, a small distance away from the parent with the better fitness value in the direction and away from the parent with the worse fitness value. Eq. (9) explains the principle of heuristic crossover.

$$\text{Child} = \text{parent }2 + \text{R} * (\text{parent }1 - \text{parent }2) \quad (9)$$

where Parent 1 has better fitness value than parent 2.

One child staggered crossover is shown in Fig. 7.

In one child staggered EAnet selects random integer n between 1 and number of variables and then selects vector entries numbered less than or equal to *n* from the first parent, and selects vector entries numbered greater than n from the average of two parents.

Two child staggered is shown in Fig. 8.

EAnet chooses three random integers m and n between 1 and number of variables and then selects vector entries numbered less than or equal to *m* from the first parent, select vector entries numbered from $m + 1$ to n, from average of two par-

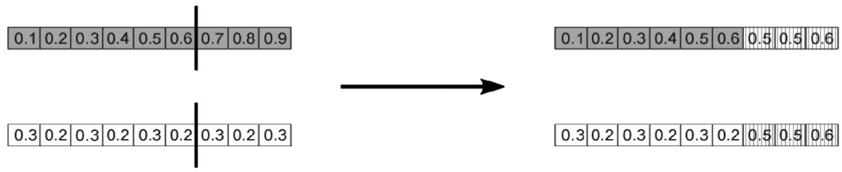

Figure 7 One child staggered crossover.

ents, and vector entries numbered greater than n to z from the first parent, and vector entries numbered greater than z from the average.

Mutation Function: the model posses 6 different types of mutation (see Table 4).

We start with Bitwise mutation is explained in Fig. 9.

Bitwise is a two-step process. First, EAnet selects a fraction of the vector entries of an individual for mutation, where each entry has a probability Rate of being mutated. In the second step, EAnet replaces each selected entry by a random number selected uniformly from the range for that entry.

Swap mutation is explained in Fig. 10.

EAnet chooses two random integers m and n between 1 and number of variables and then selects vector entries numbered m, n and switch their location.

Invert Mutation is explained in Fig. 11.

EAnet chooses two random integers m and n between 1 and number of variables and then selects vector entries numbered between m, n and invert their order.

Scramble Mutation is explained in Fig. 12.

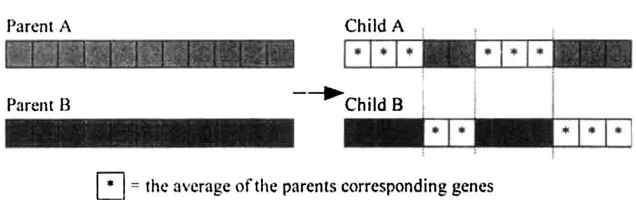

Figure 8 Two child staggered crossover.

Table 4 Mutation options in EAnet.	
Type of data	Method
ALL	Bitwise mutation
ALL	Swap mutation
ALL	Invert mutation
ALL	Scramble mutation
Gray, Real	Creep mutation
Real	Gaussian mutation

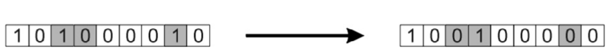

Figure 9 Bitwise mutation.

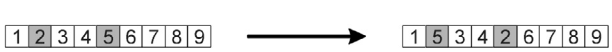

Figure 10 Swap mutation.

EAnet chooses two random integers m and n between 1 and number of variables and then selects vector entries numbered between m, n and randomly change their location.

Modified creep mutation is explained in Fig. 13.

Creep is a three-step process. First, EAnet selects a fraction of the vector entries of an individual for mutation, where each entry has a probability Rate of being mutated. In the second step, EAnet created a vector of entries been selected for mutation, where each entry has a probability of either mutated up or down. In the third step replaces each selected entry with either a one step up digit or one step down digit. It differs from original creep mutation presented by Dandy et al. [7] and Savic and Walters [8] that it allows for mutation of more than one genome in the gene.

3.1.2. Penalty functions

A new penalty function is presented in this study, taking into consideration the effect of violating points count, Max violation and average of pressure violations. The constraint violation values are normalized since large differences in the magnitude of the constraint values can lead to local minimum trapping.

$$C_p = \frac{C_T}{Npipes} \times \frac{Vio}{N_{nodes}} \times \left(p_1 \sum_{j=1}^{M} (H_{jmin} - H_j)^2 * max(H_{jmin} - H_j)^2 / mean(H_{jmin} - H_j)^2 + \left(p_2 \sum_{k=1}^{L} (V_k - V_{max})^2 * max(V_k - V_{max})^2 / mean(V_k - V_{max})^2 \right) \right) \quad (10)$$

where

C_T = Total cost of the network,
$Npipes$ = Number of pipes in network, N_{nodes} = number of nodes in net work,
Vio = Number of violating points in solution,

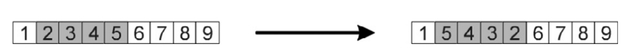

Figure 11 Invert mutation.

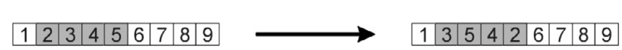

Figure 12 Scramble mutation.

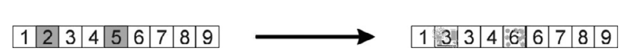

Figure 13 Creep mutation.

H_{min} = minimum allowed pressure at nodes, equals 6 m, V_{max} = maximum allowed velocity at pipes, equals 2 m/s, H_i = pressure at node (i), in meters, and V_k = velocity at pipe k, in m/s.

$$p_1 = \max(abs(V_k - V_{max})^2) \quad (11)$$

$$p_2 = \max(abs(V_k - V_{max})^2) \quad (12)$$

subjecting to the following boundary conditions:

$$H_j \geqslant H_{min}\ j \in M \quad (13)$$

$$V_k \leqslant V_{max} k \in L \quad (14)$$

$$D_{min} \leqslant D_k \leqslant D_{max} k \in L \quad (15)$$

4. Implementing IWDCU model to Kostol network

Kostol is a village located 35 km south of Abu-Simbel city. It is on the eastern side of Lake Nasser in southern Egypt. In this village a new agricultural project is under construction to irrigate an area of 5000 feddans. Kostol area consists of two major zones, the first of an area of 1540 feddans located at a relatively lower ground level and the other is of an area of 3460 feddans located in a higher ground level. The two zones are divided into equal farms each of 20 feddans. The design water duty per farm is 16 lit/s. Water from the Lake is to be lifted to a ground tank using a floating pump station. From the tank a pump station is to be constructed to deliver irrigation water through two steel pipeline networks to irrigate the two zones of the 5000 feddans. At each farm a local pump shall be used to deliver water to the farm drip irrigation system.

The IWDCU was applied to design the two pipeline networks of Kostol project.

Table 6 Total lengths of pipelines per available diameters for Kostol area.

Diameter (cm)	CHW = 125 (m)	CHW = 135 (m)
15	382	439
20	1560	1066
30	1188	1919
40	1266	2293
45	5005	5342
50	11,973	12,849
60	8392	5591
70	5776	4354
80	6485	8482
90	4224	1957
100	2021	3808
140	2138	2370
Sum weight (Ton)	6805	6683.7
Sum length (m)	51,566	51,566

4.1. Design criteria

For Kostol pipeline networks, the following design criteria are considered:

- Water duty per farm = 16 lit/s.
- Minimum allowed pressure at outlet nodes = 6 m.
- Maximum allowed velocity = 2 m/s.
- Number of standby pumps at each pump station = 1 pump.
- Design discharge for individual pumps at pump station (1) = 650 lit/s.
- Design discharge for individual pumps at pump station (1) = 900 lit/s.
- Pumps are arranged in parallel.
- Working hours per day = 11 h/day.
- Life Time cycle = 25 years.

Table 5 Best solution for each CHW value.

	Original design		Present study design			
	CHW = 135		CHW = 125		CHW = 135	
	PS1	PS2	PS1	PS2	PS1	PS2
EL	220	250	220	247	219	246
Suction WL, m	184.71	184.71	184.71	184.71	184.71	184.71
Pump head, m	35.29	65.29	35.29	62.29	34.29	61.29
Pump eff.	0.8	0.8	0.8	0.8	0.8	0.8
Duty pumps	2	3	2	3	2	3
Total no. of pumps	3	4	3	4	3	4
Q pump, m^3/s	0.650	0.900	0.650	0.900	0.650	0.900
Energy cost, EGP/K_W	0.25	0.25	0.25	0.25	0.25	0.25
C.P.S.C, million EGP	14.012	37.175	14.012	35.980	13.734	35.577
C.R.F	0.11		0.11		0.11	
C.C.P.S, million EGP	5.631		5.499		5.424	
Power, K_W	562.567	2161.670	562.567	2062.344	546.625	2029.235
A.C.E million EGP	2.730		2.630		2.590	
T.C.P.L, in million EGP	38.590		37.399		36.717	
A.C.P.L, million EGP	4.245		4.114		4.039	
T.A.C	**12.605**		**12.243**		**12.053**	
% of saving	–		**2.8**		**4.5**	
Total saving in millions	–		**4.9**		**7.5**	

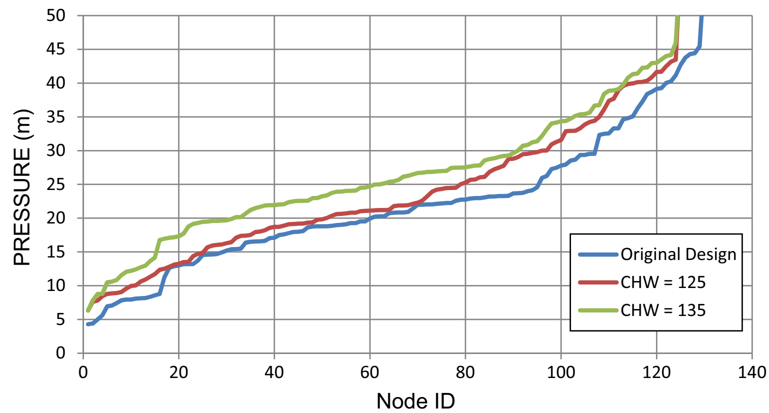

Figure 14 Comparison between nodal pressure heads before and after optimization.

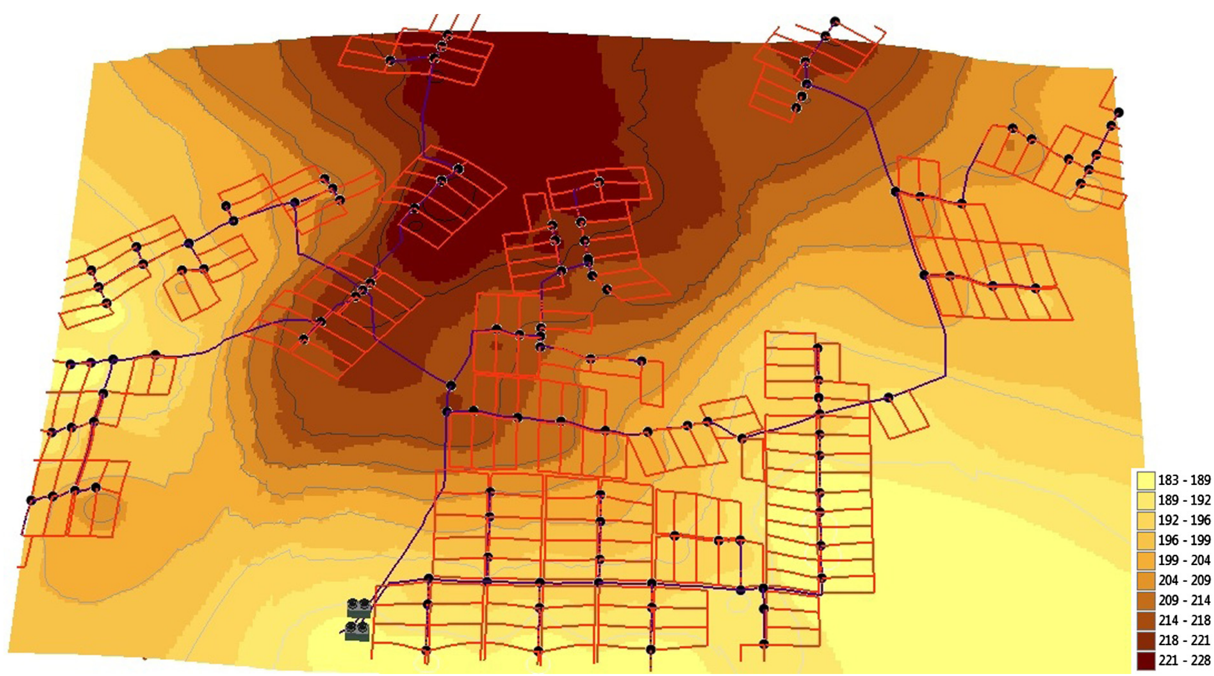

Figure 15 Kostol elevation contour map.

– Inflation Rate (%) = 10%.
– Working days per year = 356 days/year.
– Cost of energy L·E/Kw = 0.25.
– $\gamma_{\text{steel}} = 8$ ton/m^3.
– Capital cost of steel pipelines = 5500 L·E/ton including cost of pipes, transportation, installation and testing. This cost is not the current market cost, but is the cost during the construction period.

4.2. Objective function for optimal design of the pipeline network

The objective is the minimization of the Total Annual Cost of the network (T.A.C), and for such purpose the following constraint handling function is used to penalize infeasible solution and to force the search toward the feasible solution region.

4.3. Results

The program was applied for two different sets of CHW (125,135). The previous values were taken as upper, lower values of CHW according to international standards.

To ensure proper starting pump heads, the IWDCU uses GIS capabilities to identify highest withdrawal point at each zone and the distance between such node and the pump station location, and then automatically adjust the starting pump head to satisfy the minimum required head constraint.

Capital Cost of Pump Station (T.C.P.S) is taken as the sum of the following:

$$\text{C.C.P.S} = 2750 * (\text{Q} \times 100)^{0.75} \times (\text{H} \times 32)^{0.695} \tag{16}$$

where Q = total pump station output discharge, H = total pump station output head, $Power_{kw}$ = total pump station con-

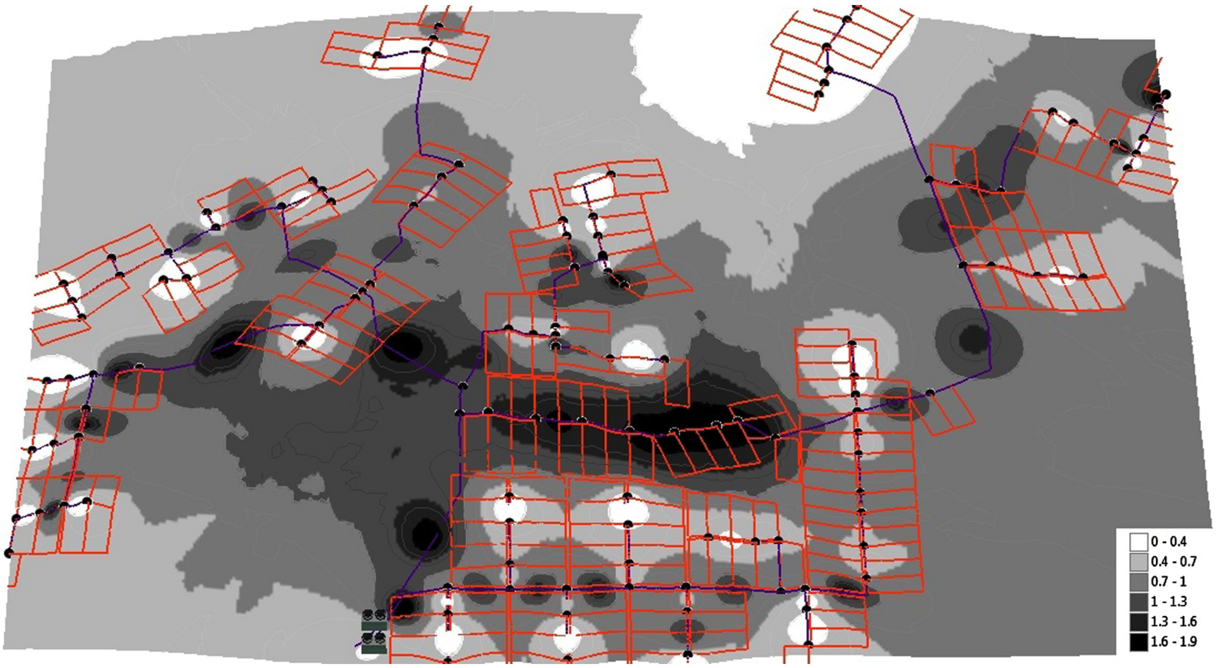

Figure 16 Kostol velocity contour map representation.

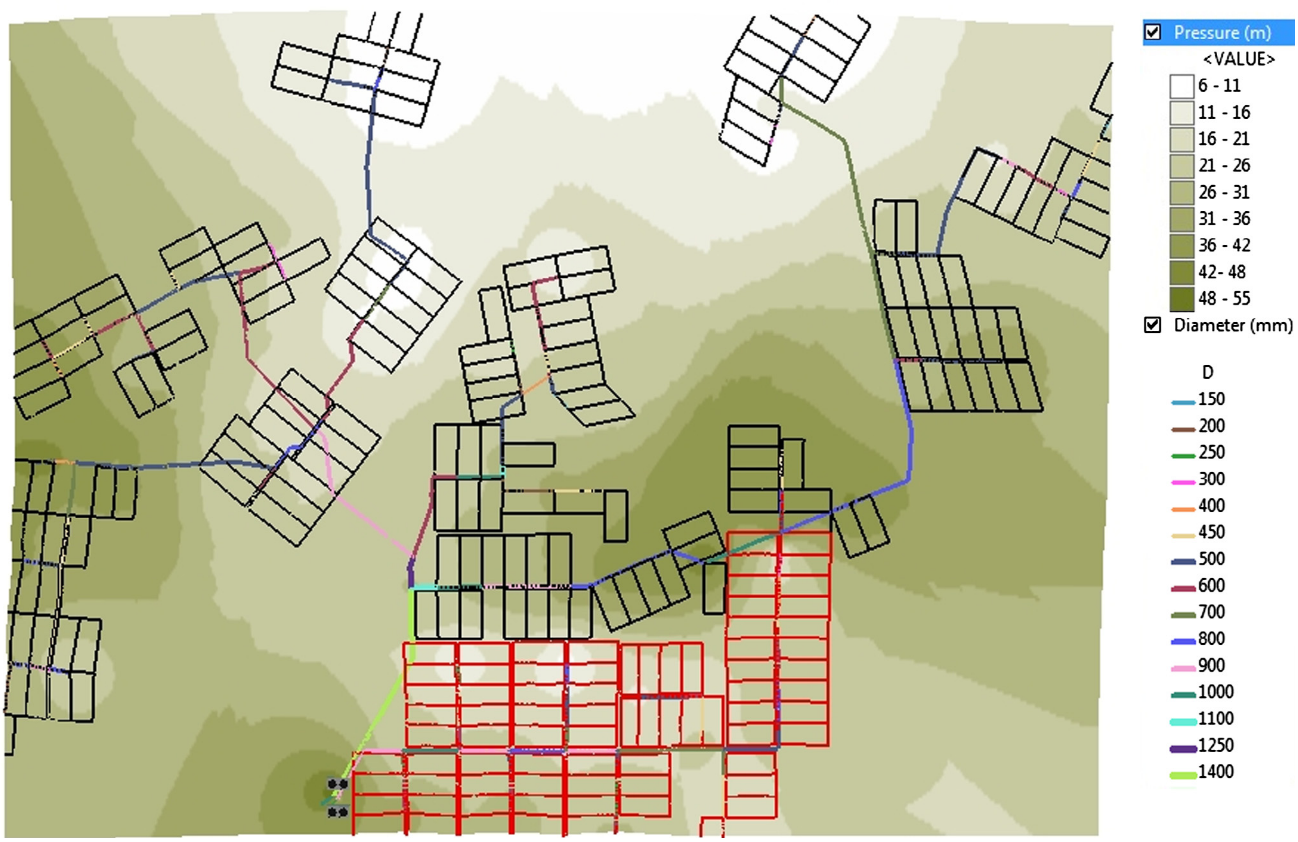

Figure 17 Kostol pressure contour map.

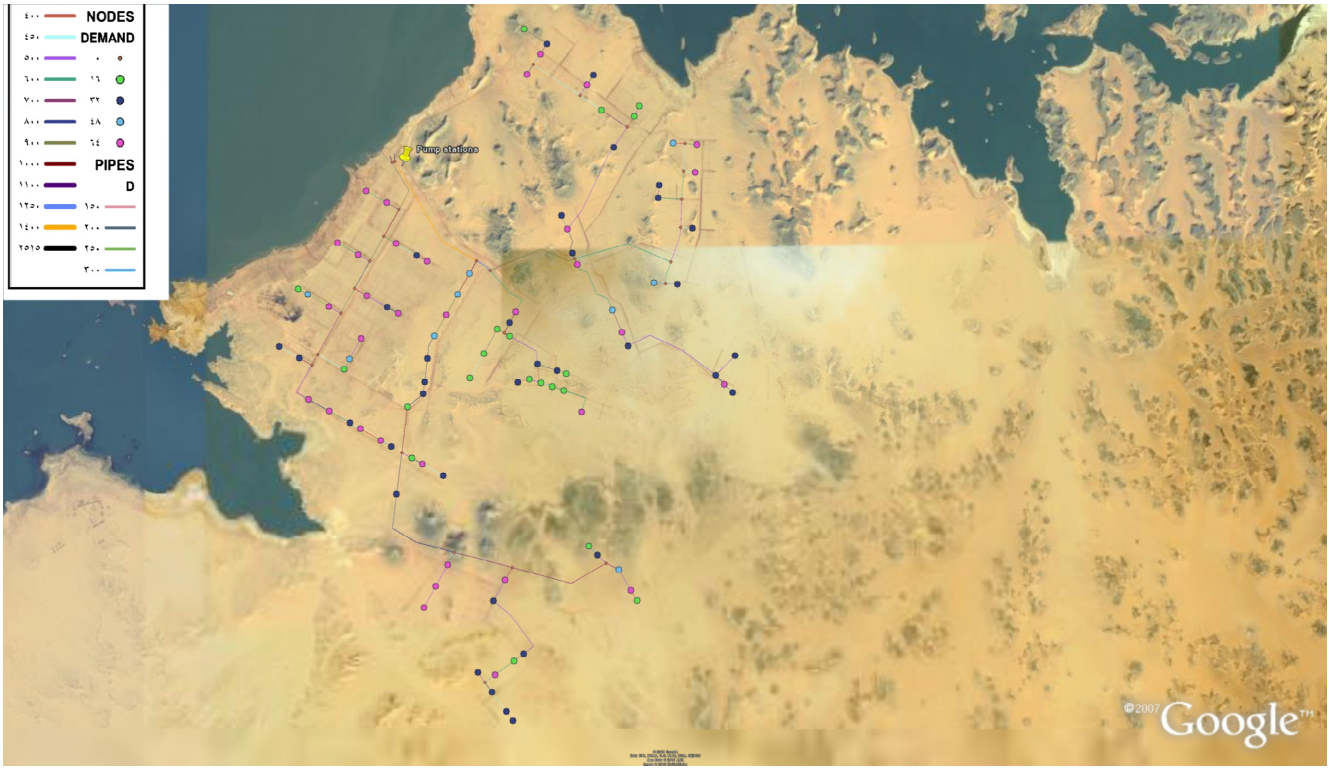

Figure 18 Kostol network over Google Maps using ArcGIS Google Maps™ link.

sumed power in kilowatt, H_P = total pump station consumed power in horse power.

Eq. (16) uses the equivalent single pump cost equation; thus, total pumps heads and discharges are used instead of multiplying by number of pumps. Such method yields better results as the pump station cost incorporates different types of costs, e.g., civil work costs, installation costs, piping and electric works. Thus doubling the number of pumps does not mean necessarily doubling the total cost of the station.

The above constant factors were calculated based on actual prices for similar projects in same geographical area at the same time.

The total cost of pipelines is taken in the following form:

$$\text{C.C.P.L} = \frac{\pi}{4} \times (d_1^2 - d_2^2) \times L_{(m)} \times \gamma_{steel} \times \text{Cost}_{(\text{L}\cdot\text{E/m})} \tag{17}$$

where d_1 = pipe outer diameter (m), d_2 = pipe inner diameter (m), L = pipe length (m).

Annual Cost of Energy is given by

$$\begin{aligned}\text{A.C.O.E} = {} & \text{working hours} \times \text{working days} \\ & \times \text{pump power} \times \text{No}_{\text{working pumps}} \\ & \times \text{cost of power}_{\text{kw/hr}}\end{aligned} \tag{18}$$

Meanwhile, the Total Annual Cost is estimated by the following equation:

$$\text{T.A.C} = \text{A.C.O.E} + (\text{C.C.P.L} + \text{C.C.P.S}) * \text{CRF} \tag{19}$$

CRF = Capital Recovery Factor, given by

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{20}$$

For calculating minor losses, two approaches were considered:

- Increasing the CHW coefficient, thus increasing friction losses in pipes (CHW = 125 case).
- Adding minor losses effect $k_{\text{minor}} = 1$; in all pipes (CHW = 135 case).

Table 5 summarizes the best result obtained by abovementioned two cases, and comparison with original design.

PS1 is the first pumping station supplying the lower ground level zone, while PS2 is the second pumping station supplying the higher ground level zone.

From Table 5, it is clear that the obtained design by IWDCU yields cheaper total annual cost results than the original design.

Table 6 summarizes the total pipeline lengths per diameter for both results.

Since original design was carried out considering CHW = 135, the comparison will be made using same CHW. In such case the T.A.C for suggested design is cheaper.

From Table 5 it is found that for total annual cost of pump-pipelines system, the suggested design is cheaper for both CHW value sets.

Fig. 14 shows that for both CHW values still the total annual cost is cheaper and produces better pressures. This shows the validity and effectiveness of suggested method.

5. GIS integration

ArcGIS [9] is used to visualize results obtained from both field and IWDCU; Fig. 15 shows contour map. In addition, Fig. 16

shows Kostol velocity contour map representation. Fig. 17 shows pressure contour map applied using both IWDCU and ArcGIS to visualize results. Finally, Fig. 18 presents Kostol network over Google Maps using ArcGIS Google Maps™ link.

6. Conclusion

Integrating data on distribution systems is a task that requires the strong commitment of several actors in a water utility. The GIS-based tool developed in this paper, with its lightweight architecture, represents a flexible approach that has been implemented in a pilot area. What was initially a tool to apply the optimal design problem. The model shows its good capability at all three sectors (Hydraulic analysis, optimal design and expansion, and GIS integration); in this regard, a computer-based water distribution network design utility, named Integrated Water Distribution Network Design and Calibration Utility (IWDCU), has been developed. IWDCU is intended to provide a comprehensive analysis and design tool for water distribution networks. IWDCU tackles two main applications in the field of Water Distribution Network (WDN), and these are ELGTnet, and EAnet.

The first sub-application (ELGTnet) addresses hydraulic analysis for both looped and branched networks. The application can handle different components including pumps, tanks, and valves considering both steady and extended period simulation. The application was applied to carryout hydraulic analysis for different pipeline networks and close results were obtained in shorter computational time when compared with the results obtained by the well-known software EPAnet.

The second sub-application Based on Evolutionary Algorithms (EAs), EAnet, is a computer-based technique for the optimal hydraulic design of WDN that satisfies both design demands and pressures at all network nodes with lowest possible cost.

For the abovementioned computer applications, mathematical modeling was combined with Geographic Information System (GIS) application for better data visualization and for best performance for the two applications. The applied GIS link reduces the time needed to collect and store data in the distribution. Transferring data between the GIS system and IWDCU models helped to optimize the engineering design and analyses.

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