



Construction of Hydraulically Balanced Water Distribution Network

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Abstract: This paper represents creating and analyzing of an adequate hydraulically balanced Water Distribution Network (WDN) based on Geographical Information System (GIS) and Epanet softwares. First a proper and functional WDN has been built and skeletonized by network analyst methodology in ArcGIS. Then the project scenario has been imported into Epanet with simple text or Epanet's readable format consisted of multiple physical or non-physical WDN objects and its characteristics. These all in order to determine analyze and simulate hydraulic parameters of WDN.

Second, we analyzed and determined water flows, water in each pipe, water flows direction as well as pressure heads at each node in the network with other required hydraulics parameters. The advantages of this method are simple math and self-correction.

Concisely, the context of this work is to use GIS and Epanet-based methodologies as well as solution of closed-loop network problems. Used continuity and energy conservation methods due to determination of pressure heads at each node, water flows and water flows direction at each pipe in the network. As a result got a satisfied hydraulically balanced and a systematic WDN appropriately as the implications of this paper approaches consequently.

Keywords: Geographical Information System (GIS); Water Distribution Network (WDN), Hydraulic, Epanet.

I. INTRODUCTION

To manage and control WDN one needs to produce Geo-database and knowledge-base to store water background data layers with features in GIS. We have produced three hierarchical geo-databases separately the structures shown in Fig.1 as (A), (B) and (C) indicate main, geometric network and topology geo-databases' structure respectively. Network has been created for Kabul city WDN in GIS tool with network utility analyst using topology and geometric analysts [1].

The statements of this valuable method are firstly the sum of pipe flows into and out of a node equals the flow entering or leaving the system through each node applied to all pipes. Secondly the algebraic sum of pressure drops around a closed loop must be zero we applied it to all of nodes. Iterations process solution has done by OpenOffice Excel solver. We found here discharge, water flows and flows direction with pressure at all nodes in all pipes of network. As

definition of hydraulically balanced network this will satisfy continuity of flow at each junction then balance the flows until continuity of potential is also achieved over each loop in the system. These solution techniques for loops balancing can be optimized correction and hydraulically balanced method too.

Afterwards having a proper GIS-WDN let import to Epanet to be analyzed and simulated the parameters, Project scenarios is imported to Epanet in a simple text format in order to do simulation for finding various WDN parameters.

II. ARCGIS APPLICATION

GIS is the best application as knowledge-base and spatial database to manage, manipulate and analyze geospatial data to develop and sustain asset management for today's water utilities [1]. Geographical Information System can be used as a key tool for making WDN. The process of creating a proper and functioning water distribution network has been

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addressed generally in our paper under the topic of 'Designing an Optimal Water Distribution Network Using GIS and Epanet, Kabul city [1].

A. Geo-database Structures of WDN in GIS

Management of water supply systems (WSS) is essential through Geo-database and knowledge-base in GIS it can be developed based on the available data on WSS. Hierarchical geo-databases' structure produced for Kabul city water supply shown in Fig.1.

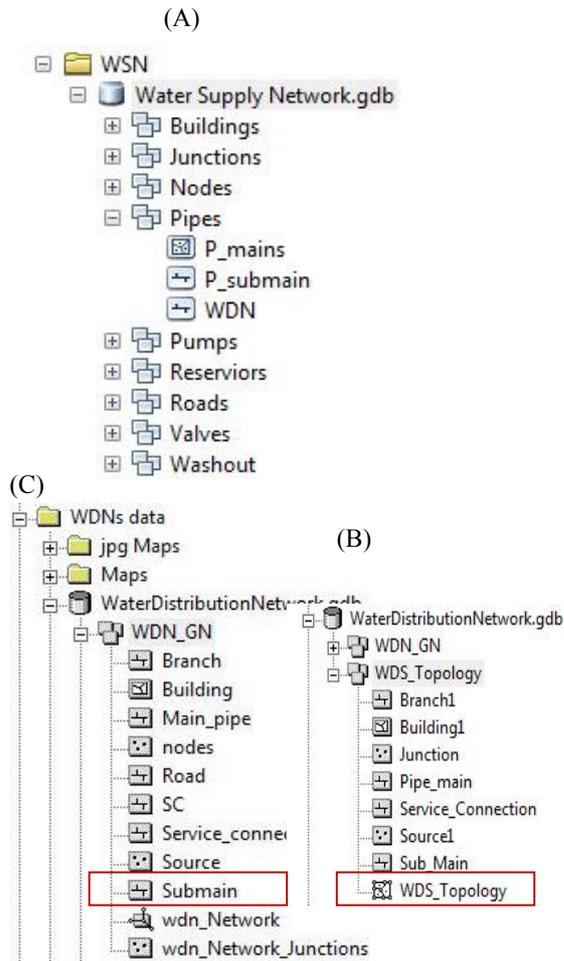


Fig.1. Geo-databases' structure for Kabul city WDN. GDB-main, GDB-Topology and GDB-GN for WDN respectively.

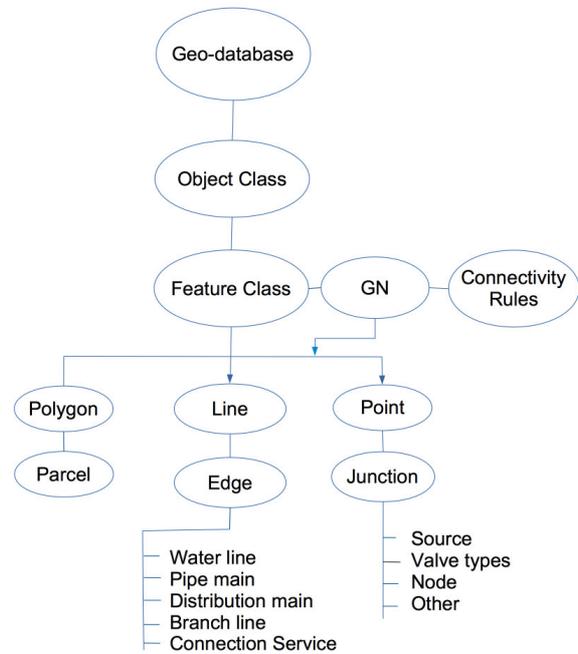
Regarding the above hierarchical Geo-databases' structure kindly refer to our journal paper, Geo-database and Knowledge Base in Arc GIS are organized and contains of the required data (raster and vector) as national level for Kabul basin [2].

B. Input Data

Input data contains of raster data such satellite images, DEM and vector data such as infrastructure info, existing and planned public utilities pipelines. With diameter and length of pipe, population users, coordinates of nodes etc. And necessary background data related to water supply, see [3] for the input data utilizing geo-database in ArcGIS.

c. WDN Using ArcGIS

This illustrates a set of creating WDN for a city GIS software-based and it's a set of geo-data-base model objects with relations and behaviors for WDN made of object classes, layers includes (polygons, lines and points) through GIS shown in Fig.2.



A set of geo-database model objects with relation and behavior for water distribution through GIS.

III. METHODOLOGY OF EPANET

A network could be consisted of pipes, pipe junctions, pumps, valves, storage tanks, and reservoirs [4]. Therefore, Epanet performs simulations of hydraulic and water quality behavior within pressurized pipe networks. Epanet tracks the flow of water in each pipe, the pressure in each node, and the height of water in each tank or reservoir during a simulation period consisting of multiple time steps [5].

This simplifies the process of using other programs, such as CAD and GIS packages, to digitize network geometric data and then transfer these data into Epanet. The format of text file looks like the following:

[TITLE]
<Optional description of the file>

[JUNCTION]
<ID label of each junction>

[PIPES]
<ID label of each pipe followed by the ID label of its end junctions>

[COORDINATES]
<Junction ID and its X and Y coordinates>

[VERTICES]
<Pipe ID and X and Y coordinates of an intermediate vertex point>

Note that only junctions and pipes are represented. Other network elements, such as reservoirs and pumps, can either be imported as junctions or pipes and converted later on or simply be added in later on. The user is responsible for transferring any data generated from a CAD or GIS package into a text file with the format shown above.

IV. APPROACH OF THE METHOD

A. Statements of The Method

1) Continuity Method

The sum of pipe flows amount into and out of a node equals to the flow amount entering or leaving the system through each node. Therefore, we have the following equation:

$$Q_a = Q_b + Q_c \quad (1)$$

Where:

Q_a = Total inflow

$Q_a + Q_c$ = Total outflow

2) Energy Conservation Method:

The algebraic Summation of pressure drops around any closed loop is zero. Therefore,

$$\sum h_l(\text{Loop}) = 0 \rightarrow \sum K(Q + \Delta Q)^n = 0 \quad (2)$$

Where:

Q = Actual inflow, ΔQ = Correction

K = Head loss, n = Flow exponent.

The general relationship must be maintained between discharges and head-loss for each pipe in loops by the following formula:

$$h_f = K.Q^n \quad (3)$$

These pressure heads loss equations has commonly been using by Epanet simulation's solutions.

- *Darcy-Weisbach Equation*

$$K = \frac{8fL}{g\pi^2 D^5}, n=2 \quad (4)$$

- *Exponential friction Formula (Hazen-William)*

$$K = \frac{10.67}{C^{1.85} D^{4.87}}, n=1.85 \quad (5)$$

Where:

C = Equivalent resistance, D = Internal pipe diameter

L = Pipe length, g = Gravitational acceleration

f = Friction factor

B. Method procedure and approach

- Network Divided into loops
- For each loops done the following steps

1. Assumed flow, flow direction, flow direction for loops whether positive (clockwise) or negative (counter-clockwise) applying continuity equation at each node. Estimated pipe flows are connected with iteration until head losses in clockwise direction is equal to the counter-clockwise direction in each loop.

2. Need to calculate equivalent resistance K for each pipe based on given parameters as demand at each node, pipe diameter and pipe length, temperature with pipe material.

3. Calculate $h_f = KQ_a^n$ for each pipe. Retain sign from (a) and compute sum for loops h_f .

4. Compute $|h_f / Q_a|$ for each pipe and sum for each loop $\sum |h_f / Q_a|$.

5. Calculate correction by the following formula:

$$\Delta = -\sum h_f / \left(n \sum |h_f / Q_a| \right)$$

6. Applying correction to Q_a , $Q_{\text{new}} = Q_a + \Delta$

7. Repeat step (3th) to (6th) until Δ becomes very small.
8. Ultimately solve for pressure at each node or junction using energy method.

In the statement portion the aims set forth, it's worth mentioning the statement of method defines inflow has to be equal to outflow at nodes. In addition the algebraic sum of pressure in close loops is zero [6].

V. Conclusion

To conclude, GIS and EPANET based methodology has been addressed for designing of an appropriate WDN. Therefore, GIS has rolled to create, manage and manipulate WDN, afterwards project's scenario has been imported into EPANET in order to analyze and determine multiples hydraulic parameters of the network.

Besides, Hardy-Cross method is used to solve and analyze two loops network as example of this academic paper's context. By performing multiple iterations until approach satisfied result.

Two hydraulic principles have been applied methodically to solve network's hydraulic parameters. First, continuity method is used and second, energy conservation methods these due to determination of pressure heads at each node, water flows and water flows direction at each pipe in the network and consequently got an optimized hydraulically balanced network.

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