Water Supply

Optimal Design of Water Distribution Networks Just an Overview

Mohammad N. Almasri



1 Optimal Design of Water Distribution Networks – Mohammad N. Almasri, PhD

Introduction

- A properly designed water distribution network (WDN) should be able to provide water at adequate pressure
- In addition, WDNs should be <u>economically</u> <u>feasible</u>, have <u>reliable operation</u> during irregular situations, and to <u>perform adequately</u> under varying demand loads



Objectives and Decision Variables in WDNs

- When designing a WDN, the <u>dominant</u> objective function is minimization of total costs under specific constraints that ought to be satisfied:
 - All demands must be met
 - Pressure at all demand nodes are to be within specified limits
 - Each demand node is to be connected by at least two pipes
 - Continuity of flow rates at nodes must be satisfied
 - Conservation must be satisfied for any specified path within the system
 - Velocity in all links must be within a specified limit
 - Pipe diameters commercially available



Objectives and Decision Variables in WDNs

- The <u>decision variables</u> include:
 - Pipe diameters
 - Pipe lengths
 - Pump sizes
 - Reservoir sizes
 - Valve locations



Optimal Design of WDNs





Example of a Branched WDN

Node	Elevation Head	Link	Length (m)
1	240	1	2,000
2	200	2	1,500
3	190	3	1,000
	180	4	2,500
	100	5	1,000
5	100	6	2,500
6	165		
7	165		



Simple Example of a Branched Network Pipe Cost

List of commercially available diameters Not a complete list

D (in)	24	22	20	18	16	14	12
D (in)	10	8	6	4	3	2	1



Example of a Branched WDN

- Determine the flow for each link by applying the continuity equation
- For each diameter, compute the velocity (C_{hw}=130)
- Do the selection of the diameters based on the velocity (0.3 to 2.0) m/s

Link	Flow (L/s)		
1	200		
2	160		
3	96 28		
4			
5	60		
6	40		

 The minimum pressure required at each supplying node is 30 m





Example of a Branched WDN The Candidate Diameters

D (inch)	1	2	3	4	5	6
24						
22						
20						
18						
16						
14						
12						
10						
8						
6						

- These are the diameters that satisfy the velocity constraint
- Not all satisfy minimum pressure constraint





Example of a Branched WDN The Candidate Diameters



An-Najah National University

Example of a Branched WDN The Optimal Solution



An-Najah National University

Example of a Branched WDN The Optimal Solution





Example of a Branched WDN The Optimal Solution





Denote by X_{ijm} the length of the pipe segment of the m_{th} diameter in the link connecting nodes i and j of length , then has to hold for all links, where the group of candidate diameters may be different for each link

$$\sum_{m} x_{ijm} = L_{ij}$$



 The head loss in segment *m* of this link is ΔH_{ijm} and can be calculated here by Using the Hazen William formula, where

$\Delta H_{ijm} = J_{ijm} \; X_{ijm}$

J_{ijm} is the gradient and Xijm is the length of the segment $J_{m} = 162.5 \left(\frac{Q}{C_{m}}\right)^{1.852} D^{-4.87}$

By applying the conservation law on a path connecting a source node i to a demand node j where the head at the final node should be greater than a specified limit H_{min,i} then we get:

$$H_i - H_{\min, j} \ge \sum_m J_{ijm} X_{ijm}$$



 Another requirement may be considered which is the non-negativity, or

Xijm ≥ 0 That is no length of any segment is to be negative.

 The cost of a pipeline is assumed to be linearly proportional to its length, and the objective function is formulated as:

Minimize
$$z = \sum_{ij} \sum_{m} C_{ijm} X_{ijm}$$



- If the optimization model was formulated with pipe diameters as decision variables, the result would be a non-linear model, because <u>head loss</u> is a non-linear function of diameter
- Selection of the <u>length of segments of constant</u> <u>diameter as a decision variable</u> has converted it into a <u>linear</u> programming model. This idea, however, raises a few points



- The list of candidate diameters should be wide enough so that the limits of the list do not constraint the selection of the diameters
- If in the solution of the linear programming, a link is made entirely of a diameter which is at the <u>end</u> of its candidate list, <u>then the list should</u> <u>be expanded in this direction</u>. The optimization should be modified accordingly and resolved



It has been proved that the optimal solution will have <u>at most two segments for each link</u>, whose diameters are adjacent on the candidate list

