Pressure Adjusted Demands

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Abstract

This paper discusses a method for hydraulic modeling of a pressure pipe network while accounting for relationships between demands (outflows) and the calculated pressure. The objective of this method is to provide a conceptually simple and reliable method for determining pressure when demands can vary as a result of pressure. A potable water system is a common example of the type of pressure pipe network being discussed.

Introduction

A water system hydraulic model calculates pressure based on input data including demands (i.e. water use or outflows) at specific locations within the water system. In a hydraulic model, demands can occur only at nodes (i.e. end/connecting points for pipes) but a node can be placed anywhere along an actual pipe (i.e. an actual pipe can be divided into multiple model pipes).

The implication is that demands are known and independent of pressure. This concept is generally valid but there are conditions where water use will change as a result of pressure:

- It takes some minimum pressure to supply water so when pressure is too low, the desired water use cannot be fully satisfied. At some point, the pressure becomes too low to supply any demand at all.
- When pressure is excessively high, more water may be supplied than is desired. Also leaks might open up.

If demands change as a result of pressure, then the calculation of pressure resulting from demands should account for such changes. Until fairly recently, commonly used water system hydraulic models have not had this capability.

Previous Efforts

Some previous efforts to incorporate this pressure/demand relationship into a hydraulic model have addressed the pressure/demand relationship concurrently with the hydraulics by using a modified solution engine. This approach requires selecting either data driven demands (i.e. no pressure/demand relationship) or pressure drive demands (i.e. including the pressure demand relationship) (1, 2). Obtaining such a solution for pressure driven demand is a difficult task (3).

Current Efforts

This paper describes a different approach for addressing the pressure/demand relationship. The hydraulic solution routines are not modified, but:

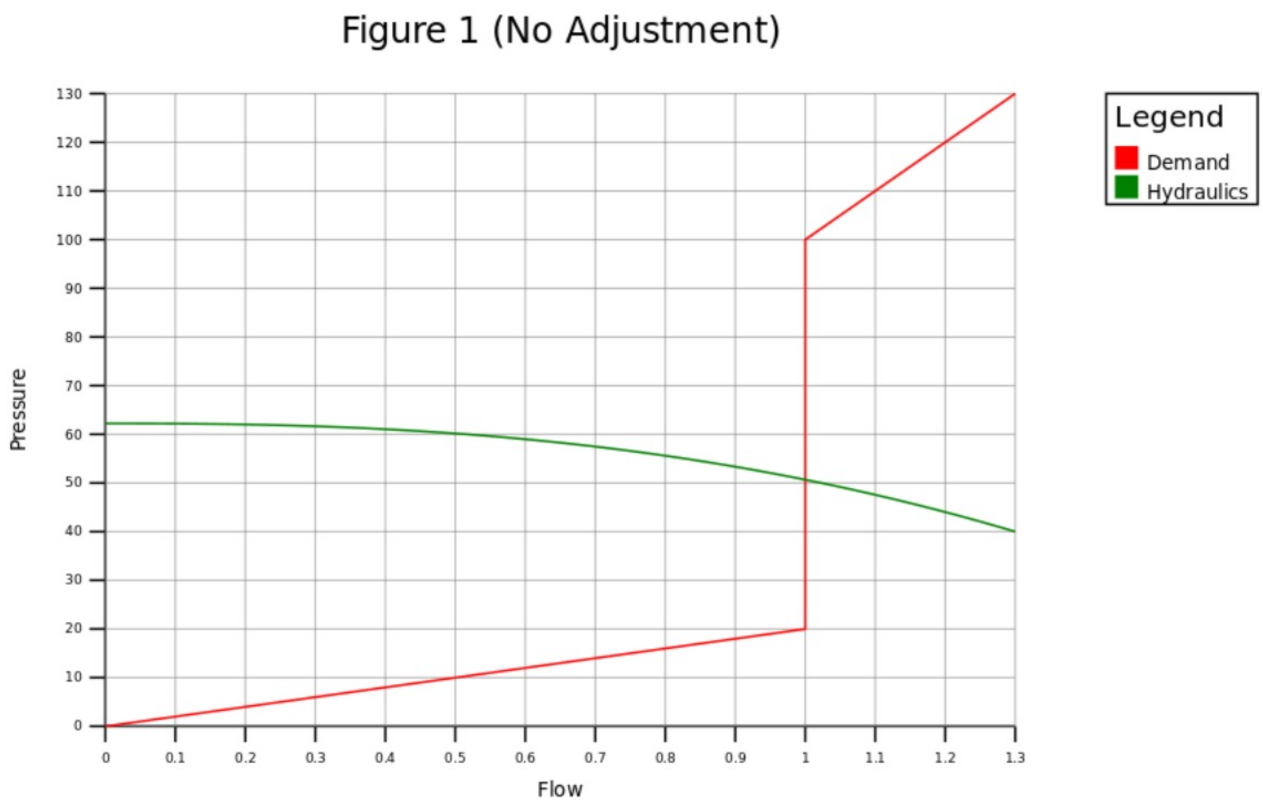
- A mathematical relationship is established between demands and pressure. This relationship is a pressure dependency.

- A procedure is called after a hydraulic solution has been obtained for a particular set of parameters (demands, pipe atus, etc) to determine whether any demands require adjustment and to estimate the adjustments.
- Node are checked to see if the pressure falls within the criteria of a pressure dependency. If so:
    1. Obtain the pressures based on the hydraulics and the pressure/demand relationship for the current demand.
    2. If the hydraulic pressure and the pressure dependency pressure are within the pressure dependency tolerance, the demand for the node is not modified.
    3. Otherwise, the demand for the node is modified based on procedures detailed below.
    4. If any demand is modified, then solve the hydraulics again and repeat the pressure dependency checks. Otherwise, accept results.

Using a pressure dependency, the relationship between demand and pressure has three components (in order of increasing pressure):

1. A component where demand increases linearly based on pressure, between pressure where there is no demand satisfied (Pressure NoQ) and pressure where demand is fully satisfied (Pressure FullQ).
2. A vertical component, between Pressure FullQ and Pressure High, where demand does not vary based on pressure.
3. A component where demand increases linearly based on pressure, as pressure rises above Pressure High.

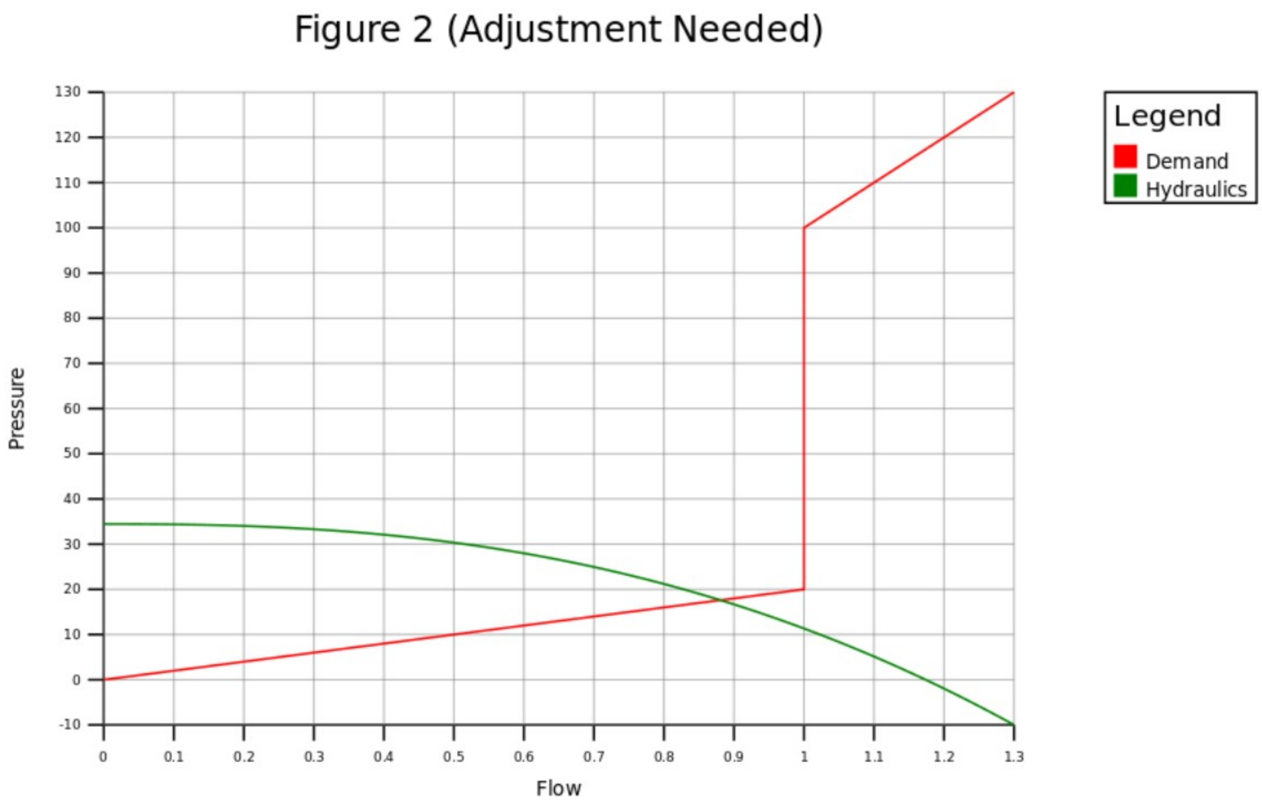
The pressure dependencies described here are incorporated in the TdhNet hydraulic model. Any number of pressure dependencies can be incorporated into a simulation and a pressure dependency can apply to all nodes or to a specified group of nodes. For a given solution, only the first pressure dependency to modify the demand for a given node will control that node. It is possible to control the order in which pressure dependencies are evaluated.



The remainder of this paper describes the procedure for modifying demands based on low pressure, but the procedure for modifying demands based on high pressure is conceptually the same.

Demands are adjusted based on the following concepts and procedures:

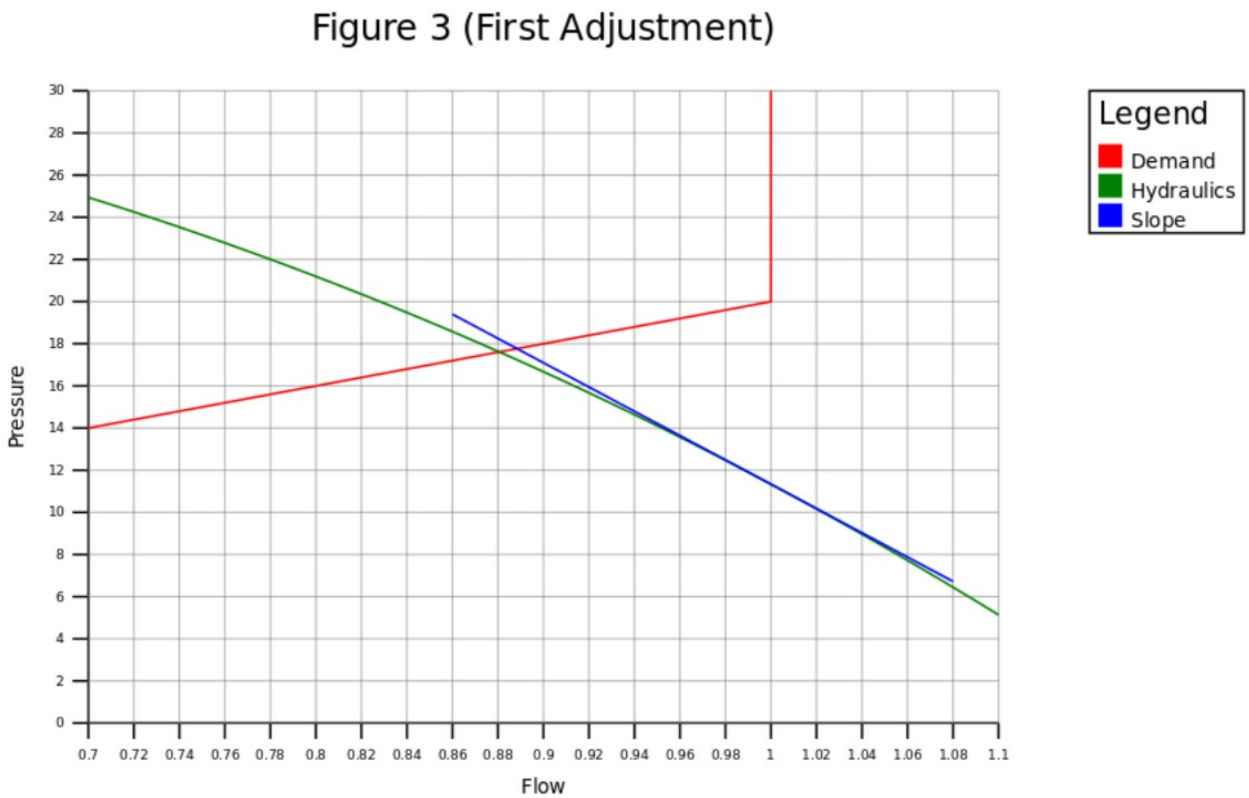
- Based on hydraulics, pressure at any given node varies with flow raised to an exponent (typically between 2 and 3), depending on the friction formula being used and other factors affecting pressure (e.g. pumps, valves and minor losses).
- For a given node, if the pressure based on hydraulics intersects the pressure dependency relationship within the vertical component, then no adjustment is needed (see Figure 1).
- If the pressure based on hydraulics intersects the pressure dependency below Pressure FullQ, the goal will be to adjust the demand to where the hydraulic pressure/flow relationship intersects the pressure dependency relationship (see Figure 2). But that goal is complicated by a number of factors:



1. In a network with many nodes, the hydraulic pressure/flow relationship at any node is affected by the demands at other nodes.
2. A mathematical expression for the hydraulic pressure/flow relationship is not readily available.
3. If a mathematical expression for the hydraulic pressure/flow relationship were available, solving for the intersection of the hydraulic pressure/flow relationship with the demand dependency relationship would be difficult.

An alternative to solving for the intersection directly is to use a linear approximation of the hydraulic pressure/flow relationship that is readily available from the hydraulic solution routines. In TdhNet, after a solution has balanced all paths by applying a flow change to each path, a new hydraulic grade is calculated for each node by starting at a fixed grade node and proceeding through the network. Since proceeding through the network, in this case, means stopping when encountering a node that was previously visited, a network tree is defined. (Note that TdhNet does not use the EpaNet hydraulic solution engine.) (4).

Since balancing the paths required calculating the slope of pressure loss vs. flow (i.e. the linearization of the pressure/flow relationship) for each pipe and then adjusting the slope of pipes common to 2 or more paths, the information to determine the pressure/flow slope from any node back to the starting fgn is available. With that we have the information to define a linear relationship between the hydraulically calculated pressure and flow.



Now, to calculate a new demand, it's simply a matter of solving 2 linear relationships between pressure and flow (see Figure 3).

equation 1: pressure dependency: p = p0 + (pf-p0)*q

equation 2: pressure from hydraulics: p = pc + (q-qc)*k

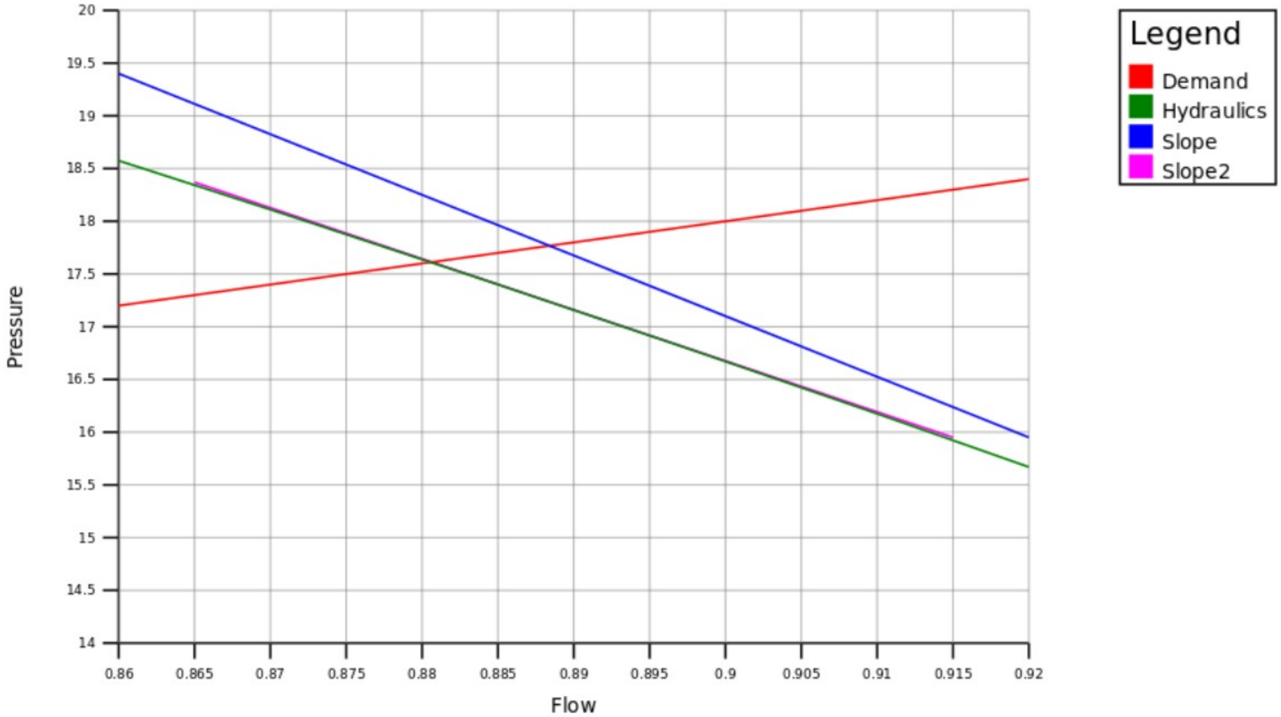
where:

q = adjusted demand (as a fraction of FullQ)
p = pressure with adjusted demand
p0 = NoQ pressure
pf = FullQ pressure
qc = demand used in hydraulic calculations (as a fraction of FullQ)
pc = pressure resulting from hydraulic calculations
k = hydraulic slope (delta p / delta q)

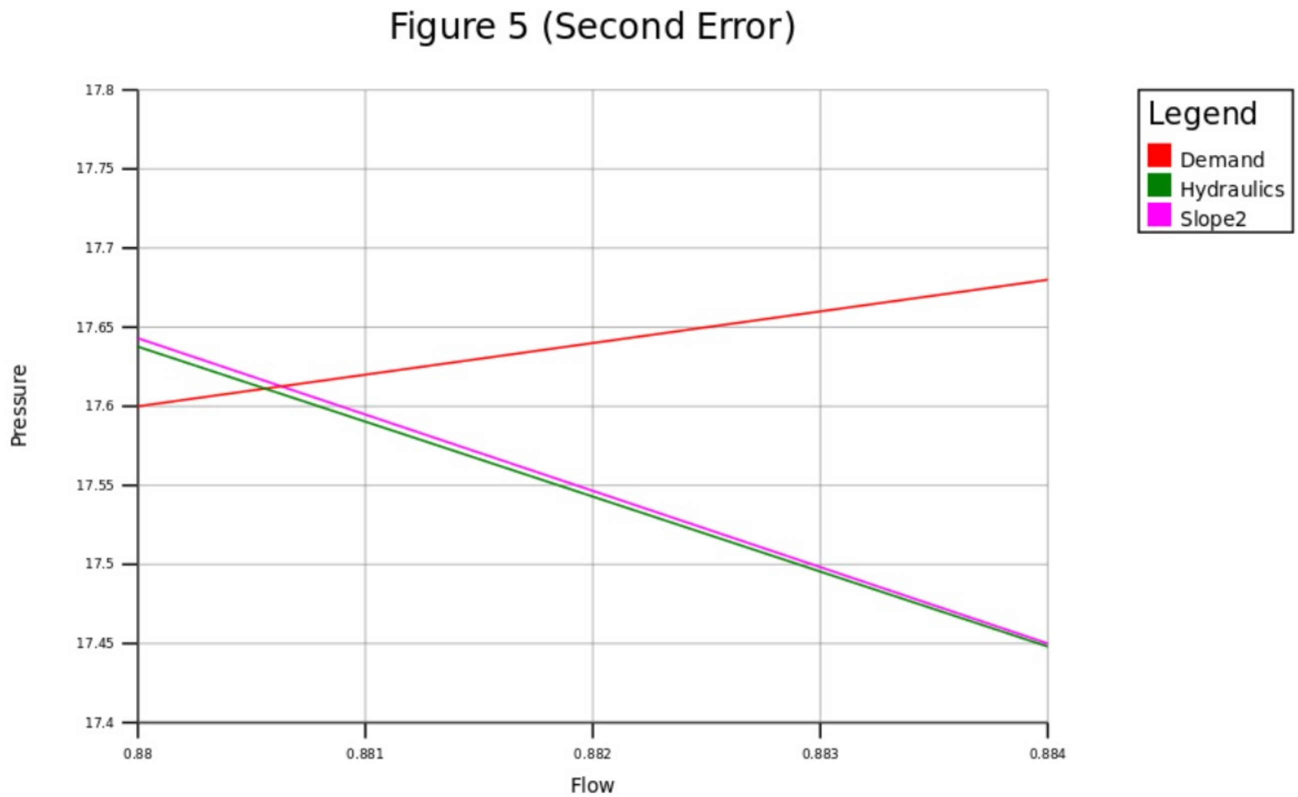
Solve for q:

equation 3: q*(pf-p0-k) = pc-p0-qc*k
equation 4: q = (pc-p0-qc*k)/(pf-p0-k)

Figure 4 (Second Adjustment)



Using this new demand, we again solve the hydraulics and repeat the process for calculating a new demand (set Figure 4) until the difference in pressure for the hydraulics and pressure dependency is less than the tolerance specified in the pressure dependency (see Figure 5).

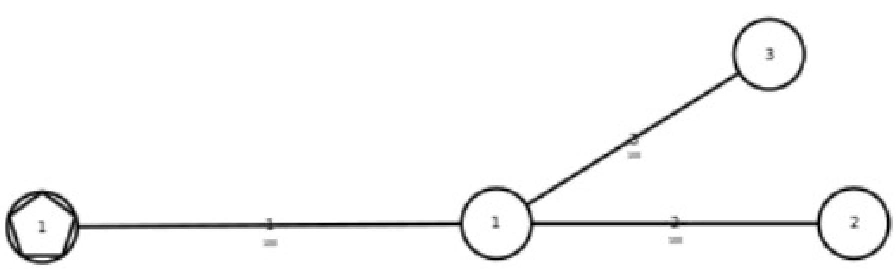


Case Studies

In the following case studies, the following pressure dependency will be active for all nodes with demand:

Pressure NoQ = 0 psi
Pressure FullQ = 20 psi
Pressure Tolerance = 0.5 psi

Case 1:



First, let's consider the most simple example of a network with just one demand needing adjustment. Referencing the diagram above, both nodes 2 and 3 have a demand of 500 gpm, but, because of elevation differences, only the demand for node 2 will need adjusting. Solving the 2 linear equations will yield a demand that is closer to the demand which solves both the hydraulics and the pressure dependency, but not necessarily within the pressure tolerance. So, the process will need to be repeated to get even closer, as many times as necessary to meet the tolerance.

Table 1: Case 1 Results

Node	**Iteration**	**Demand**	**Target Press.**	**Hyd. Press.**	**Difference**
2	1	500	20	5.8	14.2
2	2	386	15.4	14.9	0.5
2	3	381	15.3	15.3	0.0

Case 2:

Now consider the same network but with nodes 2 and 3 having the same elevation and both needing a demand adjustment. Each node will adjust its demand unaware of the other node, so the combination of the demand adjustments will tend to be excessive, resulting in a hydraulic pressure change that exceeds the target. In this situation, the consecutive pressure changes are used to calculate a dampening factor for demand adjustments.

Table 2: Case 2 Results

Node	**Iteration**	**Demand**	**Target Press.**	**Hyd. Press.**	**Difference**
2	1	500	20	5.8	14.2
3	1	500	20	5.8	14.2
2	2	385	15.4	22.6	7.2
3	2	385	15.4	22.6	7.2
2	3	424	17.0	17.4	0.4
3	3	424	17.0	17.4	0.4

Case 3:

Now let's consider a more complex network with several demands needing adjustment. (Some readers may recognize this network from EpaNet's example 3. For this case, the tanks are closed, a global demand factor of 4 is applied and pump 335 is set to speed 0.8, to obtain several nodes with pressure below 20 psi.)

Table 3: Case 3 Results

Node	Iteration	Demand	Target Press.	Hyd. Press.	Difference
101	1	760	20	17.1	2.9
103	1	533	20	16.7	3.3
251	1	97	20	16.3	3.7
253	1	218	20	13.3	6.7
255	1	162	20	17.4	2.6
101	2	688	18.1	21.1	3.0
103	2	468	17.6	20.7	3.1
251	2	81	16.8	20.8	4.0
253	2	167	15.3	17.9	2.6
255	2	145	18.0	21.9	3.9
101	3	696	18.3	20.5	2.2
103	3	481	18.1	20.1	2.0
251	3	82	17.0	20.1	3.1
253	3	175	16.1	17.3	1.2
255	3	146	18.1	21.3	3.2
101	4	751	19.8	18.1	1.7
103	4	521	19.5	17.7	1.8
251	4	95	19.7	17.9	1.8
253	4	185	16.9	15.0	1.9
255	4	154	19.1	19.0	0.1
101	5	738	19.4	18.6	0.8
103	5	513	19.2	18.2	1.0
251	5	94	19.4	18.3	1.1
253	5	182	16.7	15.4	1.3
255	5	154	19.1	19.4	0.3
101	6	723	18.9	19.7	0.8

103	6	496	18.5	19.2	0.7
251	6	90	18.4	19.3	0.9
253	6	174	15.8	16.5	0.7
255	6	158	19.1	20.5	1.4
101	7	723	19.0	19.4	0.4
103	7	496	18.6	19.0	0.4
251	7	90	18.6	19.0	0.4
253	7	174	16.0	16.1	0.1
255	7	160	19.5	20.2	0.7
101	8	723	19.0	19.4	0.4
103	8	496	18.6	18.9	0.3
251	8	90	18.6	18.9	0.3
253	8	174	16.0	16.1	0.1
255	8	160	19.8	20.1	0.3

Although each iteration of demand adjustments requires a new hydraulic solution, the hydraulic solutions are obtained quickly because there are typically only relatively small changes in demand. In particular, there are no changes to pipe status, which, in TdhNet, would require redefining the paths. Valves status is checked after demand adjustments, so, if a valve status change is needed a new hydraulic solution, including demand adjustments, will be needed.

How this works on any particular network will be dependent on the hydraulics of the network. But with the appropriate application of dampening, as noted for Case 2, it can be reasonably assured that each iteration of demand adjustments will result in improved demand estimates, so that it is only a question of how many iterations are required to achieve the specified tolerance. This method might not be best for situations that require a large number of demand adjustments, but, in general, a water system should operate with the large majority of its nodes having pressures that provide normal demand.

A primary use of pressure adjusted demands should be to avoid lower than realistic pressures when the system is not able to supply specified demands. In situations where a large number of demands have less than adequate pressure, it may be best to apply demand factors to reduce system or zonal demands.

Conclusions

Early water system models did not account for the fact that demands can vary with pressure when pressure falls outside a normal range. Previous attempts to incorporate pressure dependent demands have made significant changes to the hydraulic solution process. The method described in this paper makes no changes to the hydraulic solution process, but adjusts demands based on a pressure dependency relationship after a hydraulic solution is obtained. This method requires repeating the hydraulic solution / pressure adjustment process until a specified accuracy is obtained.

The method discussed here adjusts demands by linearizing both the relationship between pressure vs. demand adjustment and the relationship between the hydraulically calculated pressure vs. demand. Calculating an adjusted demand is then just of matter of solving 2 linear equations for pressure vs. demand. By applying a dampening factor when appropriate, it is reasonably assured that each repetition of the hydraulic solution / demand adjustment process will produce a better estimate of demand adjustments. A hydraulic solution can be obtained relatively quickly after a demand adjustment because the changes from the previous solution are relatively minor.

How this method works on particular network in any particular situation will be dependent on the hydraulics of the situation. Some case studies were examined to establish that the method will obtain a specified accuracy under a variety of conditions. How well the method performs under conditions where a large number of demands require adjustment remains to be established, but, in general, water systems should be operated such that a large majority of nodes have pressure that provide normal demand.

References

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