Water Distribution Database for Research Applications

Erika Hernadez[1], Steven Hoagland[2], Lindell Ormsbee[3],

[1]Graduate Student, Department of Civil Engineering, University of Kentucky, 161 Raymond Building, Lexington, KY 40506, email: ehernandez@uky.edu
[2]Research Assistant, Department of Civil Engineering, University of Kentucky, 161 Raymond Building, Lexington, KY 40506, email: steven.hoagland2@gmail.com
[3]Director, Kentucky Water Resources Research Institute, University of Kentucky, 233 Mining & Minerals Resource Building, Lexington, KY 40506, ph: (859) 257-1299, email: lormsbee@engr.uky.edu

ABSTRACT

The ASCE Task Committee on Research Databases for Water Distribution Systems was formed in 2013 for the purpose of developing a database for use by the water distribution system community in developing and testing new algorithms for network design, analysis, and operations. This effort has led to the identification and collection of data files and supporting narratives for over 40 different distribution systems. This paper provides an overview of the database along with instructions for how the system data may be accessed for use.

INRODUCTION

Since the late 1960's, the water distribution system research community has utilized several water distribution networks as baselines for use in comparing different analysis and optimization algorithms. One of the most widely studied water distribution systems is the New York Tunnel system, first introduced to the research community in 1969 by Schaake and Lai . Alperovits and Shamir (1977) subsequently introduced a hypothetical two-loop system that has been used to evaluate different optimization algorithms (Kessler and Shamir 1989, Geem 2006). Other commonly studied systems include Anytown, USA (Walski, et al. 1987) which was used as the basis for the original "Battle of the Network [Optimization] Models" and the Hanoi, Vietnam network introduced by Fujiwara and Kang (1990). The "Battle of the Water Sensor Networks" utilized the theoretical systems "Network 1" and "Network 2" (Ostfeld, et al. 2008). The hypothetical network of C-Town was used as the case study for the "Battle of the Water Calibration Networks" (Ostfeld, et al. 2011). EPANET's example networks "Net2" and "Net3" have frequently been used in water quality parameter estimation studies and sensor placement studies (Berry, et al. 2006, Watson, et al. 2010, Pasha and Lansey 2009, and Hart, et al. 2011). Researchers at Texas A&M have produced models of "Micropolis" and "Mesopolis," two hypothetical water distribution systems (Brumbelow, et al. 2007). Möderl, et al. (2011), developed a system that generates virtual water distribution system models. Additionally, researchers at the University of Exeter have created "Exnet," a large hypothetical system, for the purpose of testing multi-objective optimization algorithms. Most recently, Jolly et. al., (2014) developed a database of 12 models based on moderate sized systems in Kentucky that was later expanded and refined to 15 systems by Hoagland et al. (2015).

In most cases, these test networks have represented either hypothetical networks or highly skeletonized versions of larger actual systems. Unfortunately, comparison of different algorithms on the basis of a single system may lead to erroneous conclusions, since the possibility exists that any proposed algorithm may be able to take advantage of the unique state space of the particular problem while not being as robust for other systems (Maier, et al. 2003, Khu and Keedwell 2005, Marchi, et al. 2014). Secondly, while comparing the results from a new optimization routine with a previous solution may show a more optimal solution, it might also deviate from a practical or feasible solution (Walski, 2001). This kind of comparison also fails to show that the algorithm in question will provide the optimal solution for any configuration rather than just a single, highly skeletonized, example water distribution system. With increasing processing speed of modern computers, researchers are able to analyze much larger and more complex systems than ever before.

THE TASK COMMITTEE

Members of the task committee were solicited by open invitation to the research community at various ASCE conferences and by personnel invitation. A list of the current members of the committee is provided in Table 1. The committee has met on several occasions and has corresponded via email. Members volunteered to collect and submit data on different water distribution networks, including both those well know in the literature (e.g. New York Tunnel System) and other systems known only to the volunteer. Data to be submitted included an EPANET compatible data file, a narrative summary of the history and characteristics of the system, and a database of system attributes. This information is currently being collected and assimilated by the Kentucky Water Resources Research Institute at the University of Kentucky. A summary of the status of the overall database is provided in Table 2. In addition to the assembled database, Micahel Mair and Robert Sitzeufrei have developed two automatic network generators: WDS-Designer and DynaVIBe-Web, the latter of which can be accessed at http://web01-c815.uibk.ac.at/.

The current information is accessible for free from the following website: http://www.uky.edu/WDST. Additional information can be obtained by contacting the third author.

NARRATIVE SUMMARY

Narrative summaries are being developed for each distribution network. These include:

- Contributor
- Contact information

- Narrative description of the model (including schematic)
- History of the model (with references)
- Focus of model
    - Hydraulic
    - Water quality
        - Single species
        - Multiple species
    - Design
    - Operations
    - Energy
    - Reliability
    - Loss Reduction
- Type of model
    - Steady state
    - Continuous
- Status of model
    - Un-calibrated
    - Calibrated
- Contents of the model
    - Maximum daily demand
    - Number of pipes
    - Number of junction nodes
    - Number of tanks
    - Number of reservoirs
    - Number of pump stations
    - Number of pumps
    - Number of PRVs
    - Number of PSVs
    - Number of FCVs
    - Number of pressure zones
    - Number of isolation valves
    - Number of hydrants
    - Number of customers
    - Number of water meters
- Table of pipe diameters/pipe lengths

Pipe/Loop Histogram: In addition to the information above, the narrative summary is expected to contain a pipe/loop histogram as shown in Figure 1. This histogram can be developed using an algorithm developed by Hoagland and Ormsbee (2015) for the use in classifying the general overall system as a 1) branch system, 2) loop system, or 3) grid system. The classification system is summarized in Figure 2. Such a classification may assist researchers in evaluating the performance of different analysis algorithms to examine if the performance is impacted by the overall topologic structure of the distribution system.

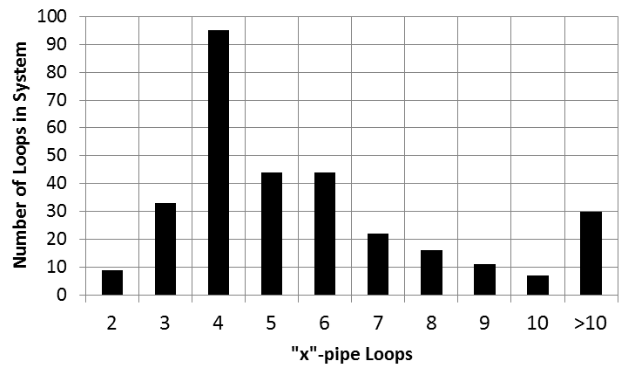

Figure 1. Pipe Loop Density Histogram (for a grid system).

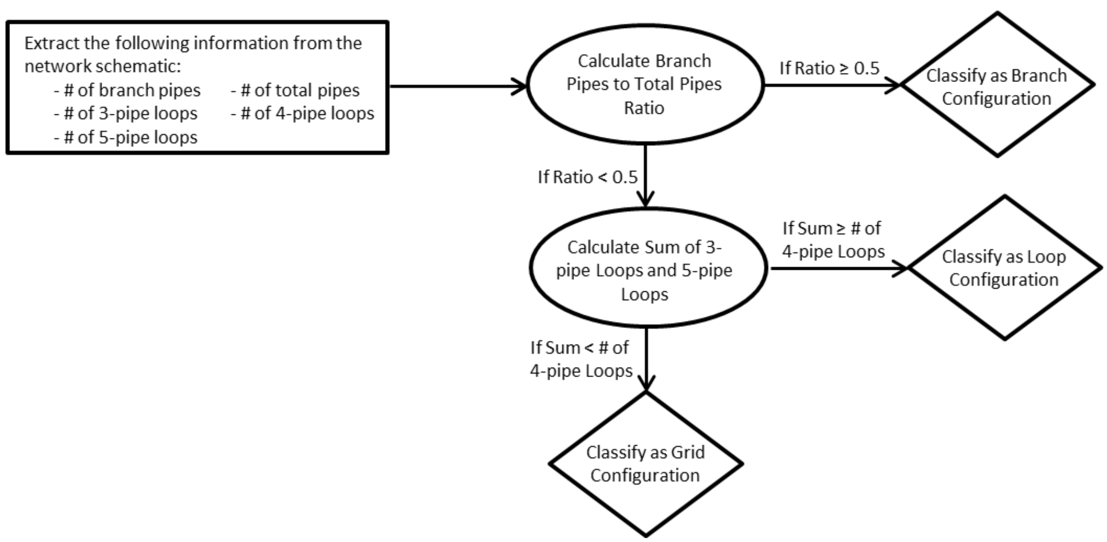

Figure 2. Classification Algorithm (Hoagland and Ormsbee, 2015)

Table 1. Members of the Task Committee on Research Databases on Water Distribution Systems

Name	**Email**
Ormsbee, L.	lormsbee@engr.uky.edu
Lee, Juneseok	Juneseok.Lee@sjsu.edu
Ostfeld, Avi	ostfeld@tx.technion.ac.il
Kleiner, Yehuda	Yehuda.Kleiner@nrc-cnrc.gc.ca
Dandy, Graeme	graeme.dandy@adelaide.edu.au
Velitchko, Tzatchkov	velitchk@tlaloc.imta.mx
Ortiz, Victor Bourguett, J.	vbourgue@tlaloc.imta.mx
Hatchett, Sam	sam@citilogics.com
Montavlo, I.del	imontalvo@ingeniousware.net
Janke, Rob	Janke.Robert@epa.gov
Mair, Michael	michael.mair@uibk.ac.at

Sitzeufrei, Robert	robert.sitzenfrei@uibk.ac.at
Simpson, Angus	angus.simpson@adelaide.edu.au
Hoagland, Steven	steven.hoagland2@gmail.com
Maslia, Morris	mfm4@dc.gov
Walski, T.	Tom.Walski@bentley.com
Lansey, K.E.	Lansey@email.arizona.edu

Table 2. Status of the Research Database

System Name	Source or Contributor
KY1	Ormsbee/Hoagland
KY 2	Ormsbee/Hoagland
KY 3	Ormsbee/Hoagland
KY 4	Ormsbee/Hoagland
KY 5	Ormsbee/Hoagland
KY 6	Ormsbee/Hoagland
KY 7	Ormsbee/Hoagland
KY 8	Ormsbee/Hoagland
KY 9)	Ormsbee/Hoagland
KY 10	Ormsbee/Hoagland
KY 11	Ormsbee/Hoagland
KY 12	Ormsbee/Hoagland
KY 13	Ormsbee/Hoagland
KY 14	Ormsbee/Hoagland
KY 15	Ormsbee/Hoagland
KY 16	Ormsbee/Hoagland
KY 17 - calibrated model	Ormsbee/Hoagland
KY 18 - calibrated model	Ormsbee/Hoagland
FOWM - Federally Owned Water Main System	Ormsbee/Hoagland
Cherry Hills/Brushy Plains, New Haven, CT (Net 2)	Lew Rossman
North Marin Water District, Novato, CA (Net 3)	Lew Rossman
Bellingham, WA (Dakin Yew Zone)	Dominic Boccelli
Fairfield, CA (Rancho Solano Zone 3)	Dominic Boccelli
North Penn Water Authority System	Dominic Boccelli
Harrisburg, PA (Oberlin)	Dominic Boccelli
New York Tunnel System	Graeme Dandy
Hanoi System	Graeme Dandy
Toms River, New Jersey	Morris Maslia
2 Loop System	Alperovits & Shamir

KYPIPE System	Don Wood
Any-town System	Tom Walski
Battle of the Water Sensor Networks	Avi Ostfeld
Battle of the Calibration Networks System	Avi Ostfeld
Micropolis	Texas A&M Univ.
Mesopolis	Texas A&M Univ.
WSS_set_2280	Sitzeufrei and Mair
Exnet System	Exeter University
Modified New York Tunnels	Graeme Dandy
Jilin Network	Graeme Dandy
Rural Network	Graeme Dandy
Extended Hanoi	Graeme Dandy
Fosspoly1	Graeme Dandy
ZJ Network	Graeme Dandy
Balerma	Graeme Dandy
KL Network	Graeme Dandy

DATABASE CONTENTS

In order to assist researchers in the select of possible network models for use in their research programs, a detailed spreadsheet database of the available data for each network file has been assembled. The attributes of the database are summarized below:

- Spatial Data
    - Geometric data
    - Elevation data
    - GIS shapefile
    - Background map
- Demand Data
    - Total system demand
    - Temporal demand curves
    - System leakage
- Pipe Data
    - Pipe diameter
    - Pipe diameter type (nominal or actual)
    - Pipe wall thickness

- Pipe material
- Pipe age
- Pipe pressure class
- Number and type of pipe fittings
- Calibrated pipe roughness
- Calibrated water quality parameters
- Customers per pipe
- Estimated pipe leakage
- Prior break history

- Junction Node Data
  - Elevation data
  - Coordinate data
  - Nodal demand data

- Pump Data
  - Pump type
  - Coordinate data
  - Elevation data
  - Pump horsepower
  - Pump operating curves

- Tank Data
  - Tank type
  - Coordinate data
  - Elevation data
  - Tank volume
  - Tank storage curve
  - Water quality data
  - Maximum elevation
  - Minimum elevation

- Reservoir Data
  - Reservoir type
  - Coordinate data
  - Water surface elevation
  - Water quality data

- Control Valves (PRVs, PSVs, FCVs)
  - Type of valve
  - Coordinate data

- Elevation data
- Operating set points

- Isolation valves
  - Type of valve
  - Coordinate data
  - Minor loss coefficient

- Hydrant data
  - Type of hydrant
  - Coordinate data
  - Elevation data

- Operational Data
  - Temporal demand data
  - Pump operational rules
  - Tank operational rules
  - SCADA data

- Water Quality Data
  - Disinfection method
  - Source concentration
  - Single or multi-species

- Booster Disinfection Station
  - Coordinate data
  - Source concentration

ACKNOWLEDGEMENTS

Funding for this research was provided by the U.S. Department of Homeland Security, Science and Technology Directorate, through a technology development and deployment program managed by The National Institute for Hometown Security, under an Other Transactions Agreement, OTA #HSHQDC-07-3-00005, Subcontract #02-10-UK.This support was greatly appreciated. The authors would also like to acknowledge the contributions of the members of the Task Committee as summarized in Table 1.

REFERENCES

Alperovits, E., Shamir,U. (1977). “Design of optimal water distribution systems”, *Water Resources Research*, Volume 13, Issue 6, pages 885-900.

Berry, J., Hart, W. E., Phillips, C. A., Uber, J. G., and Watson, J.-P. (2006). “Sensor placement in municipal water networks with temporal integer programming models.” *J. Water Resour. Plann. Manage*., 10.1061/(ASCE)0733-9496(2006)132:4(218), 218–224.K.

Brumbelow, K., Torres, J., Guikema, S., Bristow, E., and Kanta, L. (2007).“Virtual cities for water distribution and infrastructure system research.”Proc., World Environmental and Water Resources Congress, ASCE, Reston, VA.

Fujiwara, O., and D. B. Khang (1990). “A two-phase decomposition method for optimal design of looped water distribution networks”, *Water Resour. Res.*, 26(4), 539–549.

Geem, Z. W. (2006). “Optimal cost design of water distribution networks using harmony search.” *Eng. Optim.*, 38(3), 259–277.

Hoagland, S., Schal, S., Ormsbee, L., and Bryson, S. (2015). Classification of Water Distribution Systems for Research Applications, *World Environmental and Water Resources Congress 2015*: pp. 696-702.

Jolly, M. D., Lothes, A. D., Bryson, L. S., & Ormsbee, L. (2014). “Research Database of Water Distribution System Models.” *Journal of Water Resources Planning and Management*, 410-416.

Kessler, A.,and Shamir, U. (1989). “Analysis of the linear programming gradient method for optimal design of water supply networks.”, *Water Resources Research*, 25(7), 1469-1480.

Khu, S.T., Keedwell, E.(2005). “Introducing more choices (flexibility) in the upgrading of water distribution networks: the New York city tunnel network example” ,*Engineering Optimization* Vol. 37, Iss. 3.

Maier, H., Simpson, A., Zecchin, A., Foong, W., Phang, K., Seah, H., and Tan, C. (2003). "Ant Colony Optimization for Design of Water Distribution Systems." *J. Water Resour. Plann. Manage*., 10.1061/(ASCE)0733-9496(2003)129:3(200), 200-209.

Marchi, A, Dandy, G., Wilkins, A and Rohrlach, H (2014) A methodology for comparing evolutionary algorithms for the optimization of water distribution systems, *Journal of Water Resources Planning and Management*, ASCE, 140 (1), 22-31.

Möderl, M., R. Sitzenfrei, T. Fetz, E. Fleischhacker, and W. Rauch (2011) “Systematic generation of virtual networks for water supply”, *Water Resour. Res.*, 47(2),W02502

Ostfeld, A., et al.. (2008). "The Battle of the Water Sensor Networks (BWSN): A Design Challenge for Engineers and Algorithms." *J. Water Resour. Plann. Manage.*, 10.1061/(ASCE)0733-9496(2008)134:6(556), 556-568.

Ostfeld, A., Salomons, E., Ormsbee, et al. (2011). "Battle of the Water Calibration Networks." *J. Water Resour. Plann. Manage.*, 10.1061/(ASCE)WR.1943-5452.0000191, 523-532.

Pasha, M. F. K., and Lansey, K. (2009). “WDS water quality parameter estimation and uncertainty.” *Proc. World Environmental and Water Resources Congress*, ASCE, Reston, VA.

Schaake, J.C. and Lai, D. (1969). “Linear Programming and Dynamic Programming Applications to Water Distribution Network Design” Rep. 116, Hydrodynamics Laboratory, Dept. Civil Engineering, MIT Press, Cambridge, MA

Möderl M., Fetz T. and Rauch W. (2007). Stochastic approach for performance evaluation regarding water distribution systems. *Water Science and Technology*, 56 (9), 29-36.

Walski, T. (2001). "The Wrong Paradigm—Why Water Distribution Optimization Doesn't Work." *J. Water Resour. Plann. Manage*., 10.1061/(ASCE)0733-9496(2001)127:4(203), 203-205.

Walski, T. M., Brill, E. D., Gessler, J., Goulter, I. C., Jeppson, R. M., Lansey, K., ... Ormsbee, L. (1987). “Battle of the network models: Epilogue”, *Journal of Water Resources Planning and Management*, 113(2), 191-203.

Watson, J. P., Hart, W. E., Woodruff, D. L., and Murray, R. (2010). Formulating and analyzing multi-stage sensor placement problems. *Water Distribution Systems Analysis 2010-Proceedings of the 12th International Conference*, WDSA.