

The Optimatics Letter

Issue No. 2: October-December 1998 *Advances in Optimization for Water Distribution System Design & Operations*

How OGA Optimization Locates and Sizes Pipes

Today, many water utilities utilize hydraulic simulation models to plan improvements and upgrade system operations. One common approach is to periodically update the model and the system master plan based on new demand projections. This might be done every five years, while the capital improvement program (CIP) is updated annually.

Planning Questions to be Answered

A number of critical questions may face a water utility in updating a system master plan. These could include:

- how best to increase water supplies
- where to locate new storage in the system
- the best locations and sizes for new pipes
- which pipes to replace and when to do it
- how to account for uncertainty in demands
- what is the best pressure zone configuration
- how pumping operations could be improved
- how to improve drawdown in a tank
- how to best meet water quality criteria

These are very tough questions to answer. How they are answered will determine what the master plan solution will look like, how the system will perform, and how much it will cost. Distribution system optimization can

help a designer answer all of these questions. This article, however, will only describe how optimization is used to locate and size pipes.

A Simple Pipe Sizing Example

To illustrate how distribution optimization can help locate and size pipes, we will describe how the Optimatics Genetic Algorithm (OGA) is applied to a simple expansion planning problem.

Figure 1 shows the layout of the NYC tunnels problem published by Lai and Schaake in 1969. The City was looking to increase the capacity of its water supply system by adding one or more parallel pipes to the existing network of 21 tunnels and pipes. The problem can be stated as:

Where should new (parallel) pipes be located and what size should they be in order to supply the specified increased demands while meeting the minimum pressure criteria..

We are given 15 allowable pipe size choices ranging from 36" to 204" in diameter. The prescribed installed costs for pipe range from \$93.50 to \$804 per foot at any location.

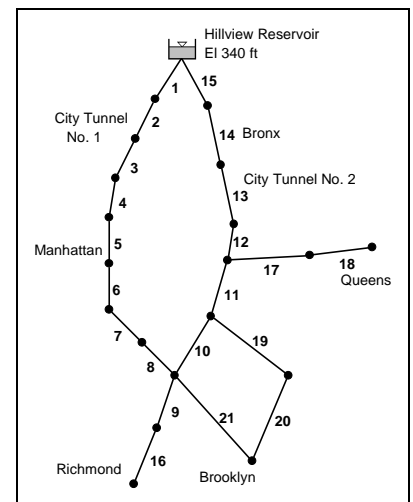


Figure 1. NYC tunnels layout.

Introduction to Issue No. 2

In our previous issue, we presented a general overview of optimization analysis of water distribution system problems. We reviewed how incredibly complex most real-world system expansion and operations problems are. For a modeler or designer whose only analysis tool is a hydraulic simulation model, it is nearly impossible to identify feasible solutions having near-minimum costs.

The newest distribution system optimization techniques provide modelers and designers with much more powerful analysis tools. Some techniques, such as genetic algorithm pipe network optimization, combine well with today's simulation programs to take advantage of their advanced hydraulic and water quality modeling capabilities. The optimization then can be applied to any type of problem the simulation model is set up to handle.

In this issue, we describe how a technique called the Optimatics Genetic Algorithm (OGA) technique can be applied to optimize pipe locations and pipe diameters. A simple network layout is chosen to illustrate the problem in its simplest terms.

\$500 Cash Prize

See Page 3 for details on our modeling challenge.

Solve a simple system expansion at lowest cost to win \$500 cash.

Simulation vs. Optimization Approach

For a designer relying on a simulation model, a normal approach would be to run a simulation of the existing system under the increased demands, examine the system deficiencies, then develop and test a series of trial solutions until a feasible alternative is found.

The approach using OGA optimization is similar, but is far more powerful. First, a simulation model of the existing system is prepared and read into the OGA program. Next, the list of allowable pipe locations and sizes are input, as well as the pipe cost data and design criteria (e.g., minimum pressures). The OGA then searches for the lowest-cost combination of allowable pipe locations and sizes that satisfy the demands while meeting the design criteria.

The OGA begins by randomly generating say 100 trial solutions (i.e., combinations of new pipes). Each trial solution is then evaluated by running the OGA's internal hydraulic solver, and by computing the cost of the solution.

The best or "fittest" solutions (i.e., those with relatively low cost and relatively good hydraulic performance) are selected to "breed" with one another to spawn a new population of offspring solutions that are likewise manipulated. In this manner, the desirable characteristics of low cost and good hydraulic performance are bred into the pipe network solutions over hundreds of generations, much like champion show horses.

The OGA search really is an "automated design" process. After specifying the objective of the search and the limits of the search space (by defining the allowable pipe choices and constraints), the OGA will automatically generate and evaluate hundreds of thousands of individual trial solutions until a set of near-optimal alternatives are found.

OGA Solutions for NYC Tunnels

In applying the OGA optimization to the NYC tunnels problem, we need a means for the OGA to choose where the new pipes should be located. We accomplish this by simply adding a zero size to the list of 15 allowable pipe sizes. The OGA can then choose a zero size for any undesirable location.

The OGA identified five feasible design alternatives for the NYC tunnels problem with total pipe costs ranging from \$38.8 to \$39.9 million (1969 cost basis). Two of the designs are shown in Figures 2 and 3. The first solution

selects pipe 15 for duplication (with a 120-inch pipe), while the second instead calls for a parallel pipe at the opposite side of the network at pipe 7 (with a 144-inch pipe). The other duplicate pipe locations and diameters are identical, except that pipe 16 is 84 inches in solution GA-1 and 96 inches in GA-2.

Since the total pipe costs are very nearly the same, the alternative solutions identified by the GA optimization search offer decision-makers a real choice in features without having to worry about cost. If it so happens that construction disruption is reduced by installing parallel pipe 7 rather than pipe 15, the decision-makers may choose solution GA-2 as the preferred option.

Figure 4 presents another interesting NYC tunnels solution identified by the OGA. This solution, which calls for only five parallel pipes at a cost of \$33.6 million, happens to be marginally infeasible. Pressures at three of the 20 nodes are slightly out of allowable range. The computed hydraulic heads at nodes 16, 17 and 19 for this solution are 258.99 ft, 271.79 ft and 254.07 ft. These heads are no more than 1.01 ft less than the specified allowable values of 260.0 ft, 272.8 ft and 255.0 ft, respectively.

The OGA thus enables the designer to present one more interesting choice to the decision-makers. If it is agreed to relax the minimum head criteria by just 1.01 ft, additional savings of \$5 million can be achieved in expanding the capacity of the system. This is a design solution that certainly would be missed without the use of a formal optimization technique.

As an aside, Lai and Schaake presented a linear programming solution to the NYC tunnels problem in 1969. They identified 18 parallel pipes to be added to the system, sized continuously from 19.52" to 133.07" at a total pipe cost of \$78.1 million. Later researchers applied other optimization techniques to this simple problem, such as partial enumeration, linear programming-gradient search, and linear programming with heuristics. Their published solutions range from \$63.6 to \$39.2 million (1969 cost basis).

Conclusion

The NYC tunnels problem demonstrates how a formal optimization technique can help a designer identify near-optimal expansion plan alternatives. This results in capital cost savings and an increased number of viable options for utility planners to consider.

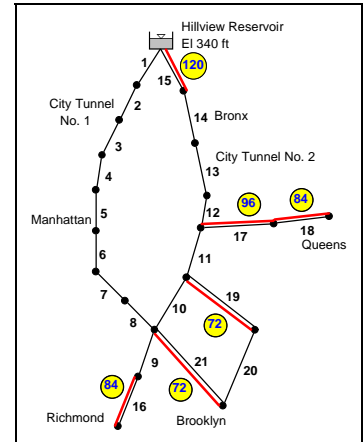


Figure 2. GA-1 at \$38.8 million.

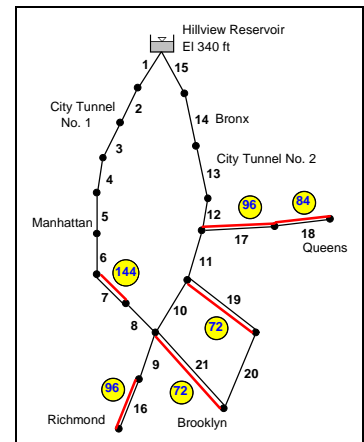


Figure 3. GA-2 at \$39.1 million.

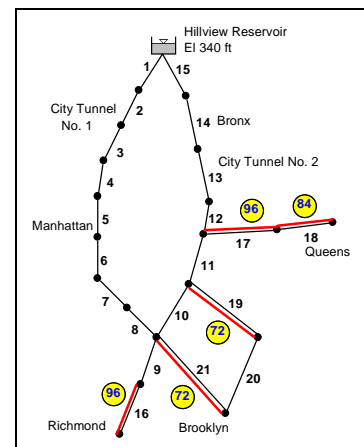


Figure 4. GA-8 at \$33.6 million.

Simulation Modeling Challenge: \$500 Cash Prize

In our introduction to this newsletter, we made a statement that some readers might like to dispute. We said:

For a modeler or designer whose only analysis tool is a hydraulic simulation model, it is nearly impossible to identify feasible solutions having near-minimum costs.

We expect there are a few modelers out there who would not accept this. They may truly believe that every master plan or expansion plan they've prepared is very close to the best that anyone could come up with.

There may also be utility managers out there who likewise believe that their master plan or CIP must be near-optimal because it came from a sophisticated computer analysis.

As we have said all along, there is nothing wrong with the capabilities of most modelers and designers. The problem is with the limitations of the simulation models that these experts rely on. No matter how good the

designer's judgment, real-world distribution problems are usually too complex to solve expertly using simulation analysis alone.

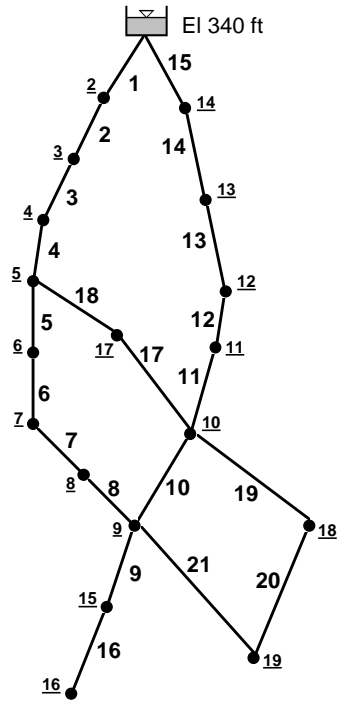
The \$500 Modeling Challenge

To prove this point, we have set up a simple test problem. We invite anyone with some spare time to input the following data into a hydraulic simulation program, then solve for a low-cost set of parallel pipes. The upgraded layout must supply the specified demands with pressures not less than 40 psi at Nodes 2-19.

The lowest cost solution of all feasible entries received by July 4, 1999 will win (or split) the \$500 prize. In July, we'll report the winning simulation design, and compare it to one or more OGA optimized solutions.

NOTE: This challenge is **only** for simulation modelers— no optimization solutions, please.

See www.frey-water.com for more details and to download a copy of the EPANET file.



EPANET INPUT FILE -- Add parallel pipes of same length to meet given demands.

[TITLE]			[PIPES]						
;Optimatics Simulation Challenge			;No.	Node	Node	Length	Diam	H-W	
			;	From	To	(ft)	(in)	C	
[TANKS]			1	1	2	4900	30	110	
;Node	Elev (ft)		2	2	3	4600	30	110	
1	340		3	3	4	4600	24	110	
[JUNCTIONS]			4	4	5	4100	24	110	
;Node	Elev	Demand (gpm)	5	5	6	4800	20	110	
2	112	2400	6	6	7	4500	20	110	
3	121	675	7	7	8	5000	16	110	
4	140	1650	8	8	9	3900	16	110	
5	145	2250	9	9	15	6250	16	110	
6	146	1875	10	10	9	5800	16	110	
7	152	1275	11	11	10	6100	20	110	
8	142	2900	12	12	11	4800	24	110	
9	120	1800	13	13	12	5900	24	110	
10	132	1950	14	14	13	6100	30	110	
11	150	1650	15	1	14	5250	30	110	
12	163	750	16	15	16	5500	12	110	
13	172	2250	17	17	10	6600	16	110	
14	170	450	18	5	17	6000	16	110	
15	125	675	19	10	18	9100	16	110	
16	132	525	20	18	19	7200	16	110	
17	158	2325	21	9	19	9200	12	110	
18	124	2100							
19	116	2175							
								[END]	

Allowable Pipe Diameters & Costs:

Diam (in)	Cost (\$/ft)	H-W C
0	0	0
6	30	130
8	36	130
10	44	130
12	51	130
16	81	115
20	105	115
24	126	115
30	165	115
36	204	115
42	248	115

Example Solution & Cost Calc:

Pipe to be Paralleled	Pipe Diam	Parallel Pipe Cost
1	36	\$ 999,600
3	30	759,000
11	30	1,006,500
12	30	792,000
13	36	1,203,600
14	36	1,244,400
15	36	1,071,000
19	16	737,100
Total pipe cost =		\$7,813,200



The Optimatics Letter



c/o Frey Water Engineering, Inc.
121 South Chestnut Ave., Suite 200
Arlington Heights, IL 60005-1817
www.frey-water.com

Bulk Rate
U.S. POSTAGE
PAID
Elk Grove
Village, IL 60007
Permit # 349

Please pass this newsletter on to key staff involved in distribution system planning and operations.

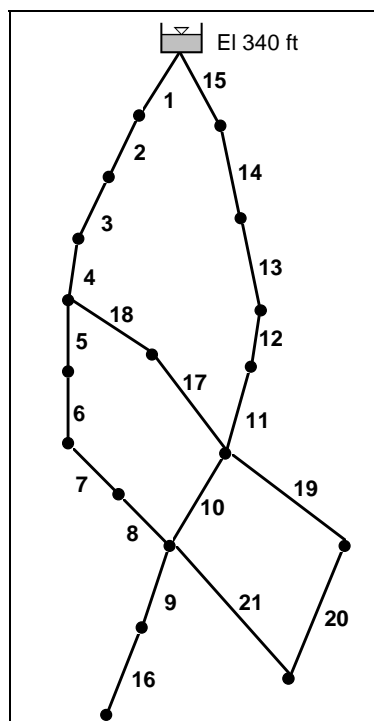
Also, please call or e-mail us to update names and addresses or to add new names to the mailing list.

The Optimatics Letter

Advances in Optimization for Water Distribution System Design & Operations

In this issue, you can read about:

- Exactly how an optimization analysis is formulated to help a designer locate and size new pipes to minimize capital improvement costs.
- Critical questions that optimization analysis can help you answer as you update a water system master plan or CIP.
- How the OGA's "automated design" process identifies not just one but several near-optimal solutions.
- How you can win \$500 even if you are just a novice modeler or spare-time modeling hacker.



\$500 Cash Prize

Solve the system expansion problem illustrated here to win.

See Page 3 for details on our simulation modeling challenge.