

# The Optimatics Letter

Issue No. 3: January-March 1999

Advances in Optimization for Water Distribution System Design & Operations

## Optimizing for System Redundancy and Phasing

Formal optimization analysis can help a designer find the best solutions to all sorts of complex distribution system planning, design and operations problems. This article describes how the Optimatics Genetic Algorithm (OGA) is being used to optimize the layout and construction phasing of a water distribution system for a large new residential development.

### A 12,000-Home Development

The conversion of vast areas of farmland to residential communities, industrial parks and shopping malls is a phenomenon occurring in many parts of the country. In most cases, the developments are relatively small and the developer submits a fairly "cookbook" water distribution plan to the local water utility, receives approval, and begins construction. The water utility may or may not review the plan using a hydraulic simulation model.

In other cases, such as ABC Estates in Arizona, the developer needs to do some serious distribution system planning to come up with an efficient and cost-effective phased implementation plan. For ABC Estates, that meant hiring an experienced consultant to prepare a water system master plan and design

the backbone transmission and distribution system. The system is to provide adequate high quality drinking water and sufficient landscape median and golf course irrigation water as the developer constructs a series of subareas to reach buildout in 6-10 years.

Figure 1 presents the consultant's preliminary layout of the backbone system. The system includes a water treatment plant with associated wet well and main pump station, two booster pump stations, and a network of pipes to ultimately serve 12,000 homes in 13 subareas. As new subareas are constructed, storage facilities will be added to the system. The entire development will cover some 4,500 acres.

### Planning for System Buildout

Planning the water distribution system began with siting the water treatment plant and developing a trial layout of pipes and supply nodes for the buildout condition. Projected demands were prepared based on definite subarea plans showing housing units, commercial and industrial zones, and parks, golf courses and open space.

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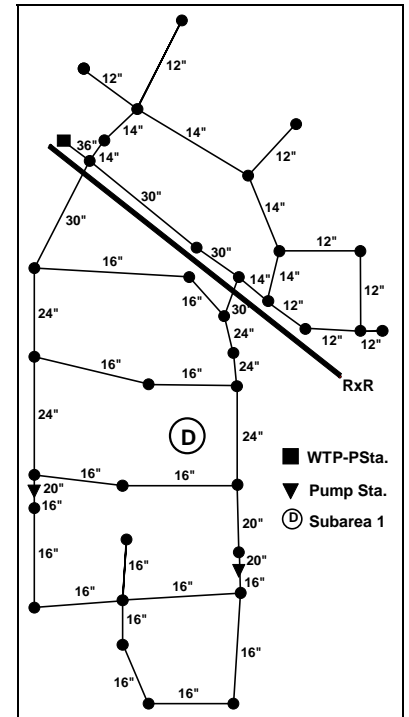


Figure 1. Original "backbone" plan.

## Introduction to Issue No. 3

In our previous issue, we noted that a water utility may face any number of critical questions as it updates its system master plan or capital improvement program (CIP). For example, we have recently been asked about how to select the best site for a new water treatment plant from among eight possible sites already identified by the city. Another utility wanted to know where to site a new storage tank to connect into the system at least cost while improving hydraulic performance. Other typical questions include how to incorporate a main replacement program into an optimized CIP, how to plan for uncertain demands given a range of growth scenarios in a master plan study, and how to minimize both planned capital improvement costs and future operating costs.

We hope to address each of these questions in future newsletters. In this issue, we explain how optimization helps address two other common planning issues, namely system redundancy and construction phasing. We describe a current study of an Arizona residential development to illustrate how the Optimatics Genetic Algorithm (OGA) can be used to sensibly plan for pipe redundancy and to optimize the staging of capital improvements (or new facilities).

### \$500 Challenge

See Page 3 for an update on the FWE/Optimatics simulation modeling challenge.

The computed water demands were 9.36, 22.88 and 33.65 mgd for the average day, maximum day, and peak hour conditions. For the maximum day plus fire flow condition, an added 3,000 gpm was assigned to each node individually.

The basic demand cases were analyzed using the following design criteria:

- maximum pressure of 100 psi
- max day minimum pressure of 40 psi
- peak hour minimum pressure of 30 psi
- max day plus fire min. pressure of 20 psi

**Specifying System Redundancy**

One interesting feature of the backbone plan in Figure 1 is that the consultant defined a system redundancy or reliability condition for the two pipes crossing under the railroad tracks. If either of the pipes goes out of service, the other pipe alone must have enough capacity to supply the area south of the tracks with the average day demand plus fire flow.

Using a simulation model, the consultant created and evaluated a series of trial solutions to find a feasible plan. Alternative pipe routes along the planned network of main roads were delineated as shown in Figure 2. Pipe layouts were prepared with assumed pipe sizes and the trial solutions checked for the basic demand conditions and the system redundancy cases.

Over many trials, the backbone plan given in Figure 1 was developed. The plan includes 34 supply nodes and 43 pipes ranging in size from 12" to 36" diameter. The total length of new pipe is 97,856 ft at an estimated installed cost of \$7,129,000.

**Optimizing the System Buildout Plan**

The consultant recognized that even for this small pipe network problem, the challenge of finding an efficient and cost-effective buildout plan was enormous. In fact, the total number of possible combinations assuming 11 pipe size choices (10"-42" plus a zero size) and 51 pipe locations (see Figure 2) is 11<sup>51</sup>, which is an astronomical number.

The consultant called for help—he requested a review of his proposed solution using OGA analysis. The OGA read in the simulation model data, the 51 allowable pipe locations, the 11 allowable pipe size choices, and the estimated installed pipe costs. A proper solution string format was developed and

initial values of the genetic search parameters prepared.

Next, the critical demand conditions used by the consultant were input into the OGA model as constraints to be met in each OGA run. Maximum day plus irrigation demand and 19 critical fire flow cases were specified. The OGA then generated and evaluated several hundred thousand individual trial solutions as it searched for the lowest-cost combination of pipes that met each demand condition and all specified design criteria.

The OGA analysis quickly identified a handful of promising low-cost alternatives. Figure 3 (back cover) depicts three of the early optimized solutions with pipe costs of \$6,497,000 to \$5,987,000 (9%-16% less than Figure 1). The next step will be to check the need for additional looping, perhaps with smaller pipe sizes.

**Optimizing Construction Phasing**

As is typical, the consultant was also concerned about construction phasing for the ABC Estates distribution system. Initially the system needs to serve only one subarea, that being subarea D. The consultant proposes to install only the 9 backbone pipes shown in Figure 4. The rest of the backbone system will be constructed in stages as new subareas are added to the development.

The consultant actually faces many choices regarding construction phasing as well. He can choose different backbone pipes to install, or perhaps temporarily install smaller pipes to be paralleled with new pipes later. But what if the County authorities insist on looping to provide system redundancy at each phase in the project? An acceptable phasing plan can be prepared using trial-and-error, but it's not likely to be the most cost-effective plan.

If the consultant asks, the OGA can next directly analyze the construction phasing problem. One approach would be to define a series of demand cases corresponding to the planned project implementation phases. In a single model run, the OGA could then search for the sequence of pipe installations that would minimize the total capital cost (or the present value) of new pipes (and pumps and valves and tanks, if appropriate). The OGA

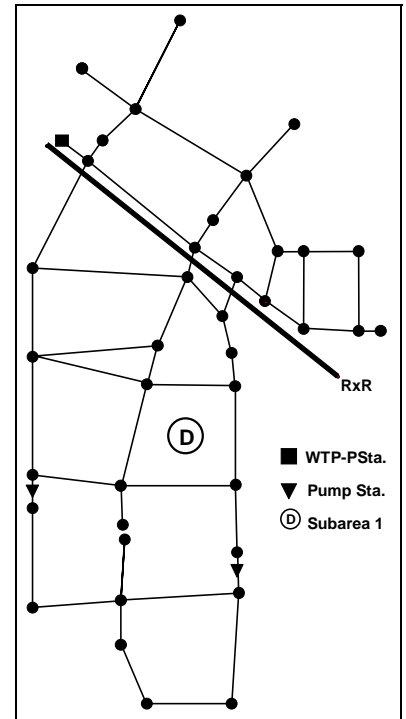


Figure 2. Allowable pipe locations.

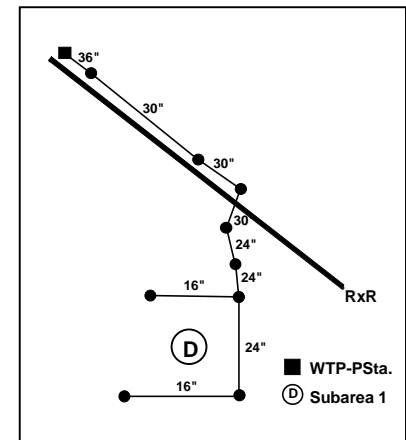


Figure 4. First phase construction.

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would identify solutions that meet not only the basic demand cases at each phase, but also meet any additional system redundancy or reliability demand conditions specified.

For ABC Estates, a construction phasing analysis might shave another \$100,000 or more off the distribution system cost. In fact, the final OGA solution may be significantly different from the proposed buildout layout due to the peculiarities of the construction phasing requirements.

**Further Refinements Using OGA**

The ABC Estates distribution system problem outlined above is quite a challenge for a designer using a traditional simulation model. It becomes even more of a challenge if the designer decides to consider several other design parameters in searching for the best phased implementation plan.

What if the designer had several choices as to where to locate one or more storage tanks in the system, (as is the case for ABC Estates)? What if the designer decided that pumping energy costs should also be taken into account (as might be done for ABC Estates)? Tank and pump locations and sizes would then be thrown into the mix, and the problem would be unmanageable for a designer relying on judgment and trial-and-error simulation alone.

This added complexity, however, would not present much difficulty for an OGA analysis. The problem formulation would still be fairly straightforward. The OGA could search for optimized alternatives directly to minimize the life cycle cost of a phased distribution system.

**Conclusion**

New developments such as ABC Estates are ideal applications for formal optimization analysis. Small network sizes and certainty of system demands make them easier to optimize than larger municipal distribution system plans. OGA optimization runs can directly consider system redundancy needs and discrete steps for optimal construction phasing. Capital and life cycle cost savings of 10%-15% or more make it attractive for developers to take the extra step of applying formal optimization analysis.

**Simulation Modeling Challenge Update**

First, we'd like to congratulate the modelers (or hackers) who have already submitted a number of excellent solutions for the Optimatics Simulation Modeling Challenge. The first came from **Ron Benson**, Vice President/Principal at **Hole, Montes & Associates** in Naples, Florida who improved significantly on the 8-pipe example solution. Rob's solution has just 7 new parallel pipes, one of which is not found in the example solution.

Ron's solution held the lead for many weeks until **Derek Linam**, Sr. Production Engineer at **St. Louis County Water Company** improved on it with a very different 9-pipe solution. Soon after, **Kirt Ervin**, Production Engineer also at St. Louis County Water sent in a somewhat similar 8-pipe solution that edged out Derek for the lead.

**An Important Rules Change**

When the Modeling Challenge was announced in our last quarterly newsletter, we stated that in the case of a tie, the \$500 cash prize would be split equally among those sending the lowest cost solution. We have decided to change that rule to encourage everyone to get their entries in earlier. The cash prize will no longer be split in the case of a tie, but shall instead be awarded to the first lowest cost entry received. We know there are a lot of modelers out there who might like a few extra bucks (like John, Mike, Randy, Tod, Dave, Joe, Madelene, Emilie, Rafael, Thomas, Kerry, Ali, Dennis, Lou, Dan and Ed), so please do send in your entries right away.

**What's This All About?**

For those of you who have not heard of the Simulation Modeling Challenge, you can read all about it at [www.frey-water.com](http://www.frey-water.com). There you can download the Challenge EPANET input and map files. The problem is simply to find the best diameters (given 11 choices from 0" to 42") for a set of parallel pipes to be added to an existing network of 21 pipes. Note that when you go about filling in the 21 blanks in the table below, realize there are a total of 11<sup>21</sup> possible combinations.

[PIPES]						
;No.	Node	Node	Length	Diam	H-W	
;	From	To	(ft)	(in)	C	
1	1	2	4900	30	110	
111	1	2	4900	?	115/130	
2	2	3	4600	30	110	
222	2	3	4600	?	115/130	
3	3	4	4600	24	110	
31	3	4	4600	?	115/130	
4	4	5	4100	24	110	
41	4	5	4100	?	115/130	
:						
20	18	19	7200	16	110	
201	18	19	7200	?	115/130	
21	9	19	9200	12	110	
211	9	19	9200	?	115/130	

**Calendar of Events**

- April 6-8** TX Section AWWA Conference in Ft. Worth
- April 18-21** AWWA IMTech Conference in New Orleans
- June 6-9** ASCE Water Resources Confer. in Tempe
- June 20-24** AWWA Annual Conference in Chicago

FWE/Optimatics staff will present papers at all four events.

**The Optimatics Letter**

*Advances in optimization for water utilities and consultants*

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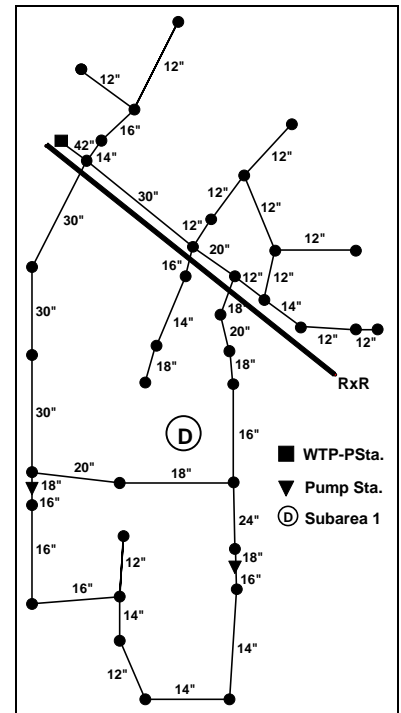
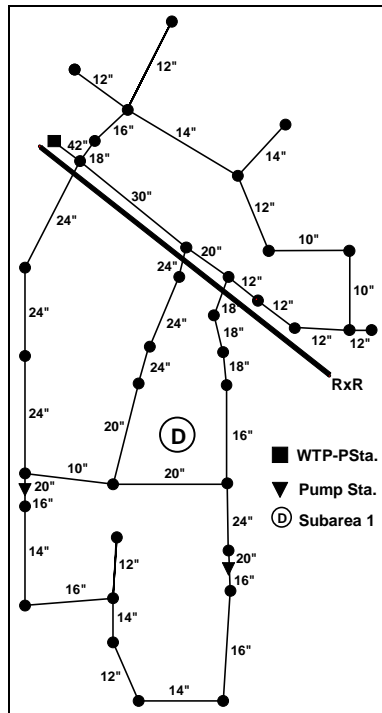
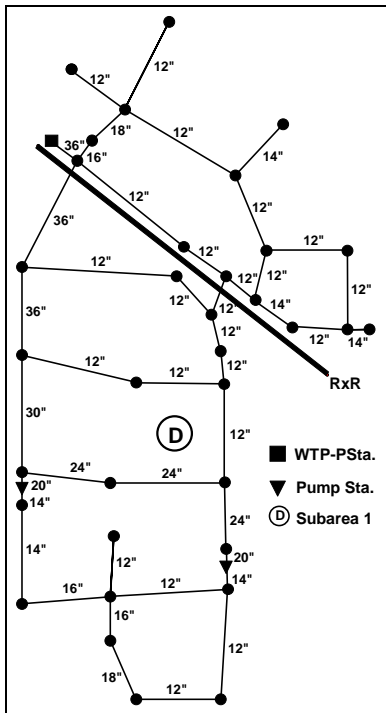
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**Figures 3a, 3b & 3c.** Three of many “backbone” solutions identified using OGA optimization for the ABC Estates development in Arizona. Capital cost savings are estimated at \$632,000-\$1,142,000 compared to the original trial-and-error simulation solution (Figure 1 at \$7,129,000). The next step will be to refine these alternative solutions to account for system redundancy and construction phasing requirements.