The Optimatics Letter

Issue No. 5: July-September 1999 *Advances in Optimization for Water Distribution System Design & Operations*

Optimization—More Than Just Minimizing Costs

In Issue No. 1 of this newsletter, we gave a working definition of optimization—the process of finding the best solution to a problem that may have many possible solutions. We also said: *The best solution might not be the lowest cost solution, but some low-cost solution that has desirable non-quantifiable features as well.*

We were reminded of these words in June at the Water Distribution System Analysis Mini-Symposium with ASCE. There were lots of papers on optimization as well as discussions on how useful some of the approaches were for real-world applications. The next week, Dr. Tom Walski ignored the rules on our Simulation Modeling Challenge problem to demonstrate why least cost is not always best. (Read about his solution on the back page.)

We agree with Dr. Walski. The aim of using optimization should not be to find the least cost solution, but to identify the best solution. The "best solution" should be flexible enough to meet the near- and long-term needs of the water utility and to satisfy all technical, economic and political criteria in the most cost-effective and resource-conscious manner.

The Optimatics Approach

Optimatics/FWE believes strongly that GA optimization is simply a tool to help designers and modelers develop better distribution system solutions. Our first step in a study is to sit down with utility and consultant staff to gain an understanding of the system, its operation, and the hydraulic model. We explain the OGA process so they realize we will be supporting the designer/modeler by running the GA search to find solution alternatives that best meet their needs.

Our aim is to find viable solutions that work for the utility, not to find some theoretical minimum cost solution they cannot implement. The optimized solutions will meet all specified design criteria, which could include minimum and maximum pressures and velocities, adequate drawdown of tanks, capacity limits for different sources and facilities, tank level and pump operating limits, etc.

Utility and consultant staff are involved throughout the OGA process which entails presenting a series of preliminary and revised GA search results to get their further input and direction. Often we find that the GA guides us toward certain solution elements we had not strongly considered at the start. In every case, the utility learns a lot about their system since they are forced to think about new possibilities for capital improvements and operations. The usually significant cost savings could be considered an added benefit of the process.

Optimizing the Challenge Problem

To solve a real-world version of the Modeling Challenge problem, we really would need to check storage requirements, tank drawdown and refilling, and alternative new and parallel pipe routes for various steady state and EPS demand conditions. An OGA optimization could be easily formulated to handle all these conditions and more, including different growth patterns and rates, reliability needs and water quality limitations. The best solution alternatives would then emerge for consideration by the decision-makers.

> *Your success has made it more important to warn users about the differences between the least cost and best design.*
>
> *Dr. Tom Walski*

Modeling Guru Tom Walski's Warning

As we had hoped, the Water Distribution System Analysis Mini-Symposium at ASCE's June conference in Tempe provided plenty of lively discussion on optimization of water systems. Experiences in optimizing chlorine booster station locations, pump scheduling to minimize energy costs, hydrant selection for flushing, as well as using GA for model calibration were described.

On the last day, Dr. Tom Walski issued "a wakeup call to optimization modelers in general." Tom later confided that he was concerned about the lack of success of optimization methods presented in research but never tested in the real world. Happily for us, Tom told FWE: *I'm very impressed with the work that you and your colleagues have done. In fact your success has made it more important to warn users about the differences between the least cost and best design.*

Simulation Modeling Challenge Results

The Simulation Modeling Challenge is now closed. We'd like to acknowledge the efforts of the dozens of modelers and hackers who spent time testing themselves on the Simulation Challenge problem.

We had a good time with this and really enjoyed everyone's comments. Most people said they spent too much time trying to find lower cost solutions. Others said they got frustrated: if they revised their solution in one area of the network, things fell apart in another area. Several people thanked us saying the Challenge was fun and they learned first-hand how difficult modeling is.

Our Winner—Reginald Soenen

The winning solution was submitted by Reginald Soenen from Belgium in March. His 6-pipe solution is shown in Figure 1. Reginald's approach was straightforward:

> *I tried to duplicate all the pipes of the left part of the loop with the highest option and then try to reduce each of them until the pressure constraints failed. So I have found a solution of $M 5.744 (Pipes 1, 2, 3, 4, 5, 6, 7 and 19 duplicated with 30, 24, 36, 36, 24, 20, 24 and 12 inches pipes). Then I tried the same procedure with the right part of the loop and found a cheaper solution of $M 5.484.*

That sounds easy. Reginald will be receiving his $500 prize as soon as we can get it to him.

Special Mention—Angela Hoover

Special Mention goes to Angela Hoover of Harford County Water & Sewer in Maryland. Angela spent countless hours of trial-and-error to find a different mix of pipe sizes for the same 6 parallel pipes shown in Figure 1. She tied the low-cost $5,483,850 solution (in May) by sizing Pipe 11 at 30" rather than 36" and Pipe 14 at 30" rather than 24".

Angela also identified another promising mix of sizes for the same 6 pipes. The cost of that solution came in at $5,474,100 or 0.2% lower than the lowest cost solution. Unfortunately when the solution is simulated using EPANET, the computed pressure at Node 18 is 39.93 psi which pushes this solution just outside the feasible range. Sorry Angela.

Other Feasible Solutions

The table on Page 3 lists the names of the top 10 finishers, their organizations and their best solutions. The top 10 solutions range from $5,483,850 to $5,956,200. The No. 10 solution comes in at 8.6% or $472,350 higher in cost than the lowest cost solution.

The table also presents a sampling of other entries with capital costs ranging up to 16.3% or $895,650 higher than the lowest cost solution. These modelers happened to choose a less promising set of parallel pipe locations or could just not get the right mix of pipe sizes. Given limited time and also not knowing how good their solutions were relative to an unknown "optimal solution", a 16% higher capital cost is not surprising.

OGA Optimization Analysis Results

So, did our OGA optimization find any lower cost alternatives? Actually we tried very hard to beat our simulation winner. We ran 30-40 million trial solutions using different starting values, population sizes, mutation rates, etc., but the lowest cost solutions found by the OGA were the same ones identified by Reginald and Angela.

In spite of our failure to find a lower cost solution using the OGA, the Challenge contest did succeed in demonstrating how difficult it is to find cost effective solutions using only a simulation program. Nearly half of the entries we received had solution costs more than 10% higher than the lowest cost solution. If a water utility were not lucky enough to get a "top 10" solution, the extra 10-15% spent on new pipes in this simple case would provide them no extra value at all.

The OGA did identify a range of low-cost solution choices that we hadn't seen before. Four of the OGA-optimized solutions are depicted in Figures 2-5. Each presents a different mix of parallel pipes with costs not more than 2.5% higher than the lowest cost solution. This result demonstrates the power of the GA search to find the best solution alternatives. Care must be taken, however, to ensure the problem is properly formulated so that all promising design approaches are encompassed in the GA search space.

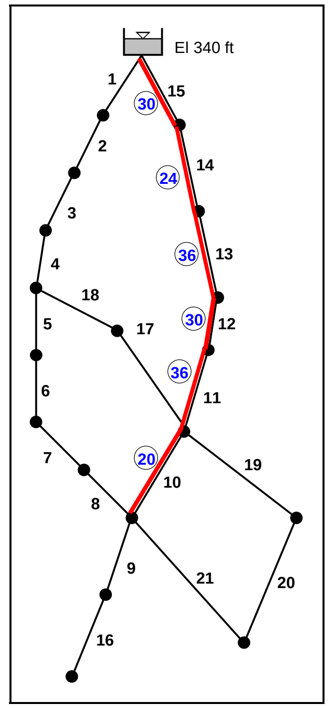

Figure 1. Reginald Soenen's winning $5,483,850 solution.

Name	Organiz.	No.of Pipes	Diameter of Selected Parallel Pipes in inches 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Estimated Cost	% > Low Cost Sol.
Reginald Soenen	Belgium	6										20	36	30	36	24	30							$5,483,850	0.0%
Angela Hoover	Harford County, MD	6										20	30	30	36	30	30							$5,483,850	0.0%
Martin Dix	Boyle Engg, CA	6										24	30	30	30	30	36							$5,580,300	1.8%
Tim Hirrel	Washington Suburban	8	30	30	30	30						24							20	24	12			$5,646,900	3.0%
Tom Bean	Pitometer Assoc., TX	7										24	30	30	30	30	30				6			$5,648,550	3.0%
Kirt Ervin	St. Louis County, MO	8	30	30	30	30						20							24	24	12			$5,663,700	3.3%
Alex Blandon	Seattle Water, WA	9			30	24	8					24	30	30	30					10	12			$5,679,300	3.6%
Terry Hui	GVRD, Canada	7			24	30						24	36	30	36						12			$5,691,000	3.8%
Derek Linam	St. Louis County, MO	9	30	30	30	30	24	20	24											16	16			$5,933,400	8.2%
Joseph Dong	Stoner Assoc., PA	6										30	36	36	36	36					8			$5,956,200	8.6%
Modeler V	--	10			24	30		12				24	30	24	24		24			10	12			$5,960,700	8.7%
Modeler W	--	6										16	30	36	36	36	36							$5,974,500	8.9%
Modeler X	--	8							8	12		16	30	30	36	36	36							$6,166,200	12.4%
Modeler Y	--	12	12	12	30	16	16					20	30	24	36	12				8	12			$6,379,500	16.3%
Modeler Z	--	11	24	24	30	30	20	10					24	30	30	30	30							$7,741,350	41.2%
Example Solution	FWE/ Optimatics	8	36		30								30	30	36	36	36				16			$7,813,200	42.5%

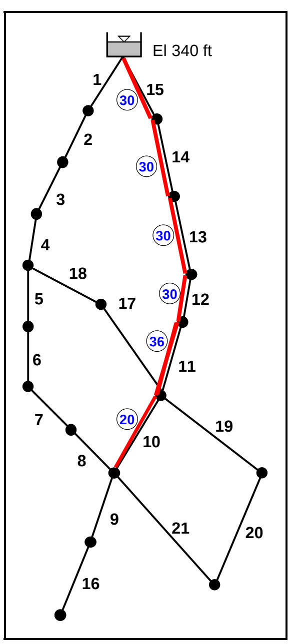

Fig. 2. GA+0.1% ($5,491,650)

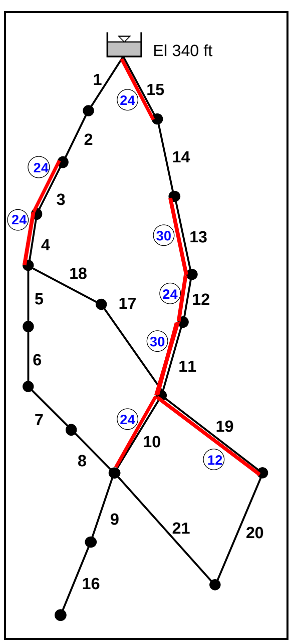

Fig. 3. GA+1.0% ($5,537,400)

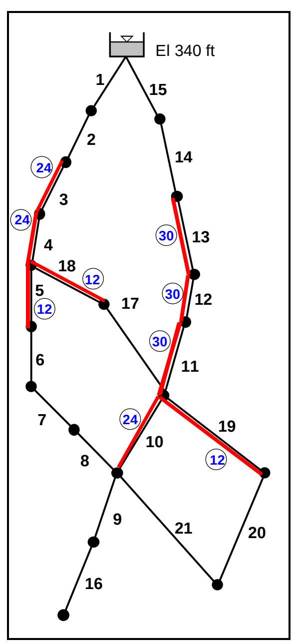

Fig. 4. GA+2.4% ($5,613,900)

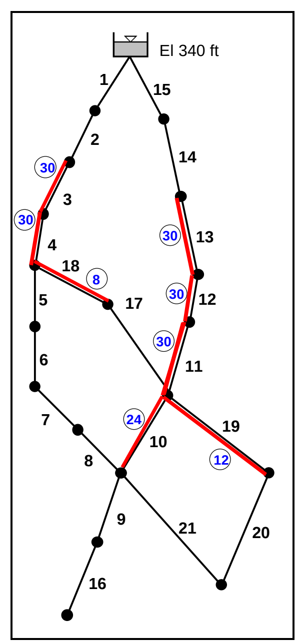

Fig. 5. GA+2.5% ($5,618,400)

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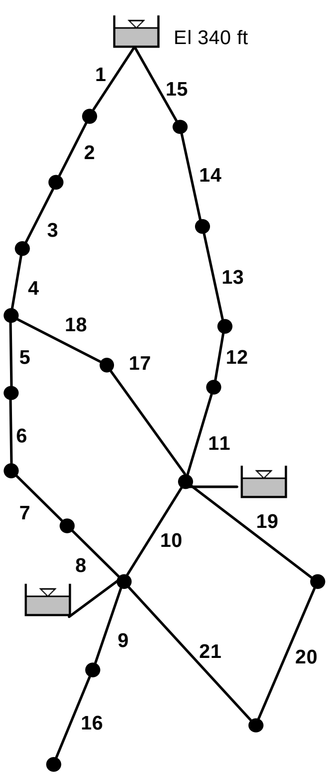

Walski's Solution

Dr. Tom Walski says he did some out-of-the-box thinking to come up with this unique solution to the Simulation Modeling Challenge.

Tom added 6.5 MG equalization storage at the south end with 4.0 and 2.5 MG tanks. That should cut peak flows down sufficiently so the existing piping will work.

Tom estimates the elevated tanks and connecting pipes would cost about $3.6 million. The solution would improve reliability and minimize pressure fluctuations. We love the solution, Tom, but it is outside the Challenge rules.

$500 Winner

Pages 2-3 present the Challenge winner and other simulation and OGA solutions.