The Optimatics Letter

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Optimatics GA Proves Ready for Prime Time

Research on applying genetic algorithm (GA) optimization to pipe networks began in 1990 at the University of Adelaide in Australia. Since 1995, the GA technique has been successfully applied to a variety of distribution problems of increasing size and complexity.

The latest study to optimize a Comprehensive Water Distribution Master Plan for the City of Grand Prairie, Texas clearly demonstrates that GA optimization is now achieving its full potential. The Optimatics GA (OGA) considered both capital improvement and operations costs as it simultaneously optimized locations and sizes of new pipes and tanks, set points for flow control and pressure reducing valves, pumping hours for 14 pumps, water supply rates from 3-4 treated water sources, and more.

Grand Prairie's Master Plan GA

Our last newsletter (Issue No. 8, April-June), presented Part 1 of the Grand Prairie Master Plan GA story. It explained how the Director of Utility Services specified that genetic algorithm optimization be used in the alternatives evaluation phase to identify the most cost-effective solutions. Optimatics/Frey performed the GA study as subconsultants to CH2M Hill who first prepared a system-wide hydraulic simulation model and growth and demand projections to year 2025.

Some quick statistics on the system hydraulic model: 2,100 existing and 300+ possible new pipes, 1,830 nodes, 4 source connections and 11 wells, 19 pumps at 8 pump stations, 10 existing and 16 new storage sites, and 10 flow control and pressure reducing valves.

The City's current population of 117,000 is projected to double by year 2015 as growth explodes in the largely undeveloped southern half of the City and new areas in the south are annexed. Average day and maximum day demands are projected to increase more than 200% to 51 MGD and 92 MGD for the expanded future service area.

OGA Objective & Search Constraints

The aim of the OGA analysis was to identify several near-optimal Master Plan solutions that meet the year 2015 demand conditions while satisfying all system design and performance criteria. An extended period simulation (EPS) of the 2015 maximum day was evaluated in the GA search.

The OGA objective function was to minimize project life cycle costs, namely:

- the cost of new transmission mains
- the cost of new & parallel distribution pipes
- the cost of new ground & elevated storage
- the present value of water purchase costs from 3-4 sources having different unit rates
- the present value of pumping energy costs

System performance criteria were input as constraints in the OGA search, including:

- minimum allowable pressures of 35 psi for max day & 20 psi for max day plus fire flow
- maximum allowable pressures of 65 psi in older areas and 110 psi in all other areas
- tank water levels must draw down at least 5 feet and return by the end of the EPS day
- tank water levels must remain above ⅓ full
- minimum total storage volume of 92.6 MG
- pumps must operate in their normal range

(Continued on page 3)

The OGA simultaneously optimized locations and sizes of new pipes and tanks, set points for flow and pressure regulating valves, pumping hours for 14 pumps, water supply rates from 3-4 water sources, and more.

Q & A: Does Optimatics/Frey sell the OGA program or simply use it to perform studies?

Optimatics/Frey Water Engineering provide specialized GA consulting services to water utilities and consultants. We link the Optimatics GA program to an existing calibrated hydraulic model to efficiently search for the best overall mix of capital improvement, operations, energy and/or water quality decisions.

The OGA study process requires considerable expertise and experience. For this reason, we are not comfortable simply selling our fully-capable OGA program to a client. However, we can offer to lease the OGA program to a client once we customize it to study a particular distribution system problem. We would then train the client's staff in using the OGA to optimize additional demand cases or to perform sensitivity analyses on the optimized solutions.

Summary of OGA Results for Five Optimized Grand Prairie Year 2015 Solutions

Features of the solutions	SOLUTION GP15	SOLUTION GP16	SOLUTION GP17	SOLUTION GP18	SOLUTION GP19
The five scenarios differ based on new ground storage site choices and assumed supply rates from Midlothian:	1. South Dallas 2. Highway Interchange 3. Mansfield Road 4. Northern Robinson	1. South Dallas 2. Highway Interchange 3. Mansfield Road	1. South Dallas 2. Highway Interchange 3. Northern Robinson	1. South Dallas 2. Mansfield Road 3. Northern Robinson	1. South Dallas ***** 2. Highway Interchange 3. Mansfield Road 4. Northern Robinson
Midlothian max.day supply rate	15-18 MGD	15-18 MGD	15-18 MGD	0 MGD	5 MGD
Cost summary ($ million):					
Transmission pipe costs	16.68	16.04	16.83	10.59	14.33
Distribution pipe costs	32.85	33.67	32.38	65.66	53.07
New tank construction costs	17.20	16.70	16.70	16.70	15.10
TOTAL CAPITAL COSTS	**66.74**	**66.41**	**65.92**	**92.95**	**82.50**
PV water purchase costs	357.32	348.17	354.39	292.53	311.04
PV pump power costs (50 yrs)	5.71	5.39	5.52	2.91	2.94
TOTAL ON-GOING COSTS	**363.03**	**353.56**	**359.91**	**295.44**	**313.98**
TOTAL COSTS	**$429.76 million**	**$419.97 million**	**$425.83 million**	**$388.39 million**	**$396.48 million**
New storage volumes (MG):					
Ground storage tanks	42.0 (4 sites)	43.0 (3)	43.0 (3)	43.0 (3)	45.0 (3) *
Elevated storage tanks	5.0 (3 sites)	4.0 (3)	4.0 (3)	4.0 (3)	1.5 (2)
TOTAL NEW STORAGE	**47.0 MG (7)**	**47.0 MG (6)**	**47.0 MG (6)**	**47.0 MG (6)**	**46.5 MG (5)**
Length of new pipes (mi):					
Transmission pipes	7.1	7.1	7.1	4.5	7.1
Distribution pipes	38.3	37.7	35.7	47.4	44.6
(No. of distribution pipes)	(64 pipes)	(58)	(58)	(65)	(65)
TOTAL NEW PIPES	**45.5 mi**	**45.1 mi**	**42.9 mi**	**52.1 mi**	**51.9 mi**

***** The OGA chose not to add a new tank at the South Dallas site in run GP19 (i.e., the OGA assigned that tank variable a zero size).

Five Distinct Scenarios Optimized

Facing rapid growth in the south and dramatic demand increases, the City needed to carefully analyze its near- and long-term options for water purchases, pumping operations and ground versus elevated storage. A series of OGA runs were thus conducted to optimize five distinct scenarios as directed by the City (see summary table on Page 2).

Grand Prairie currently purchases most of its water (96%) from Fort Worth via a connection in the northwest and from Dallas via two connections in the northeast and southeast. The City pays Fort Worth and Dallas $1.20 and $0.90/1,000 gal, respectively. The option to purchase water via a new connection to Midlothian in the south at $1.90/1,000 gal was also considered in the optimization.

Three of the final OGA runs (GP15-GP17) explored year 2015 solutions where the City would contract for significant water purchases (15-18 MGD maximum day) from the new Midlothian connection in the south. Runs GP18 and GP19 explored solutions with no water being purchased from Midlothian or only 5 MGD maximum day. Other differences between the five final scenarios relate to the allowable choices of three or four ground storage sites in the OGA search.

The table indicates that optimized solution GP18 has the lowest life cycle cost, i.e., new pipe and tank capital costs plus the present value of water purchase and pumping energy costs. Total capital costs are lowest for runs GP15-GP17, where substantially less new distribution pipe is required. These solutions, however, exhibit the highest operating costs due to greater supply levels from the relatively expensive Midlothian source.

Grand Prairie's Preferred Solution

After careful review of the five optimized alternatives, the City selected GP18 as its preferred Master Plan solution. Besides exhibiting the lowest life cycle cost, there were other attractive features to solution GP18. First, the City did not want to commit to purchasing substantial supplies from Midlothian, preferring to leave open the option of supplying its southern area from other sources.

The City also liked the fact that GP18 called for new 24"-36" pipes running north-south along Highway 360 to complete the west side of a large loop around the southern area. These pipes were not selected in solutions GP15-GP17.

In addition, solution GP18 featured a total of 34 MG of new ground storage situated on a ridge overlooking the southeastern portion of the Grand Prairie service area. Up to 12 MG of new storage could be built at the existing ground storage tank farm that receives water from South Dallas. The remainder of the new storage would be sited at a suitable location further south on the ridge.

Finally, the operating cost savings for solution GP18 are significant. GP18's estimated year 2015 annual water purchase plus pumping costs are $16.8 million (1999 $), compared to $17.2 million for solution GP19 and $19.4-$20.1 million for solutions GP15-GP17.

Additional OGA Analysis Benefits

Other aspects of the Grand Prairie OGA study are interesting to note. The OGA search was configured to possibly redefine the system's pressure plane boundaries by opening any number of existing closed pipes crossing boundaries, and adding up to five new pipe connections between adjacent high flow pipes. The number of pressure planes was thus reduced from four to two in solution GP18.

In addition the OGA evaluated the validity of existing and new regulating valves and pump stations. Solution GP18 thus demonstrated that the existing Egyptian Way pump station could be eliminated; this recommendation was heartily adopted by the City.

Conclusions

The City and its consultants recently prepared an AWWA technical paper on the Grand Prairie Master Plan GA. The conclusions stated that (1) the OGA optimization results definitely justified the effort and expense involved, (2) significant cost savings were achieved, (3) both capital improvement and system operating costs were optimized, (4) the OGA identified a range of optimized solution alternatives, and (5) the OGA process fit in quite naturally with the normal sequence of Master Plan tasks.

GA optimization can help find better solutions:

- *Master Plans & CIPs*
- *Phasing improvements*
- *Correcting deficiencies*
- *Demand uncertainties*
- *System operations*
- *System rehabilitation*
- *System reliability*
- *Emergency planning*
- *Energy optimization*
- *Water quality design*

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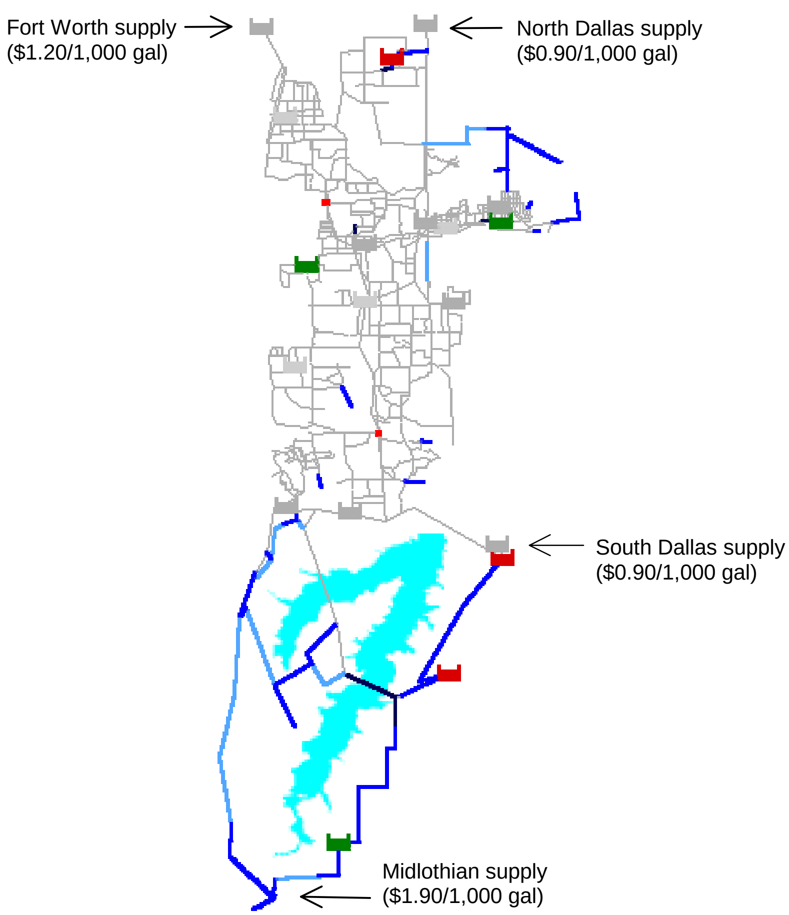
Advances in Optimization for Water Distribution System Design & Operations



City of Grand Prairie, Texas
Water Distribution Master Plan

Optimatics GA optimization was applied to identify five distinct solutions that minimized capital improvement and system operating costs simultaneously.

City's preferred year 2015 solution features:

- 67 new pipes (52 miles) from 300+ choices
- 3 new ground storage tanks given 4 sites
- 3 new elevated tanks from 12 site options
- optimized supply rates given 4 sources
- optimized pump schedules for 14 pumps
- optimized settings for PRV and FCVs
- reconfiguring of pressure plane boundaries
- decommissioning of one pump station
- meeting minimum & maximum pressures
- exercising of tank levels to ensure quality