The Optimatics Letter

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Advances in Optimization for Water Distribution System Design & Operations

Pipeline Design Optimization

The pipeline design problem presented in this article is a 230 km (143 mile) water pipeline in New South Wales, Australia. As in most engineering studies, the problem exhibits its own unique requirements—but there are still plenty of elements that are common to all pipeline designs. Hopefully you will find the Optimatics GA (OGA) optimization approach described here useful and highly cost-effective for your own future pipeline and conveyance studies.

Darling Anabranch Water System

The Darling Anabranch Water System aims to provide water to 70 agricultural properties for domestic, irrigation and livestock needs. (An anabranch is a diverging branch of a river that later rejoins the river further downstream.)

The area is currently served by open channel diversions via 17 weir pools resulting in annual water losses of 47 GL (12,400 MG) and significant degradation of the ecosystem. The pipeline project will enable very efficient water delivery, and also return the anabranch to its pre-regulated condition.

The Department of Commerce took the lead in preparing a design for the major pipelines and about 80 km (50 miles) of minor pipes to supply the users' individual storage tanks. Two pump stations on the River Murray in the south and on the Darling River in the north-east will provide year-round supplies to the system. (See Figure 1 on next page.)

The original Anabranch Water System design by Commerce was prepared assuming a 50%-50% supply ratio between the Murray Pump Station and Darling PS. A minimum allowable pressure of 13 m (18 psi) was specified for outlet nodes in the design.

Original Solution Life-Cycle Cost

Optimatics started by first reviewing the original design using the hydraulic model provided by Commerce. A baseline solution cost was estimated considering both capital and lifetime operating costs:

- Murray PS, Darling PS and treatment plant costs
- cost to bring electricity to the two PSs
- replacement costs for the two PSs
- new pipe costs
- new (optional) booster PS costs
- energy costs at two major PSs
- energy costs at any selected booster PSs

The life-cycle cost for the Commerce design was calculated, including pumping energy costs—which we cannot report here since the bidding process is currently underway.

Scope of OGA Optimization

After reviewing the original baseline solution, the study aimed to develop a least-cost solution that met the same criteria. The study next aimed to optimize new solutions for various other design scenarios of interest. The OGA optimization was thus used as a strategic management tool to allow the Client to effectively assess different network solutions during the planning process.

For each OGA scenario, both a normal demand case and an emergency demand case were considered. The normal demand case set all nodes at peak demand with both the Murray PS and Darling PS pumping water.

(Continued on page 2)

The OGA was used as a strategic management tool to investigate a wide range of design options.

Nine optimized designs were prepared achieving project life-cycle cost savings of 12% to 18%

The emergency demand case represented either a drought or algal bloom condition during which no supply would be available from the Darling River. Demands were reduced by 50% but all supply had to come from the Murray source. To aid in this emergency case, one or two booster pump stations (from among seven possible locations) were located and sized in the OGA optimization. (See Figure 2 on back page.)

The results of each set of OGA optimization runs was reviewed with the Client to solicit input for new ideas or modifications to the constraints. In the final set of runs, the OGA investigated alternate locations for the Murray River PS that resulted in reduced pipe length.

OGA Problem Formulation

The Anabranch Pipeline optimization problem was formulated to minimize project life-cycle costs while fully supplying demands under normal and emergency cases, and meeting all design and performance constraints. The constraints included minimum pressures at all nodes, maximum pump heads, and limits on the ratio of water pumped from the Murray PS and Darling PS.

The OGA was linked to a simple EPANET representation of the Anabranch Water System. The hydraulic model consisted of 234 junctions (55 were demand nodes), 2 source water basins, 234 pipes (total 314 km or 195 mi), 2 source pump stations, and 7 possible booster stations.

A common set of decision variables was used in the OGA analysis for each optimization run. The OGA searched for the best mix of pipe diameter, pipe material and pressure class, booster pump station location (up to two only), booster pump sizes and pressure heads, and source pump sizes and pressure heads.

OGA Scenarios & Runs

Optimatics conducted three major sets of OGA runs. Four scenarios were optimized in the first set of runs including a baseline case with 13 m (18 psi) required at each node, a case requiring 30 m (42 psi), and two cases with reallocated demands.

Following a detailed review of the initial solutions, the Client requested three new scenarios be optimized. The first investigated yet another variation in demand pattern. The other two evaluated the option of introducing

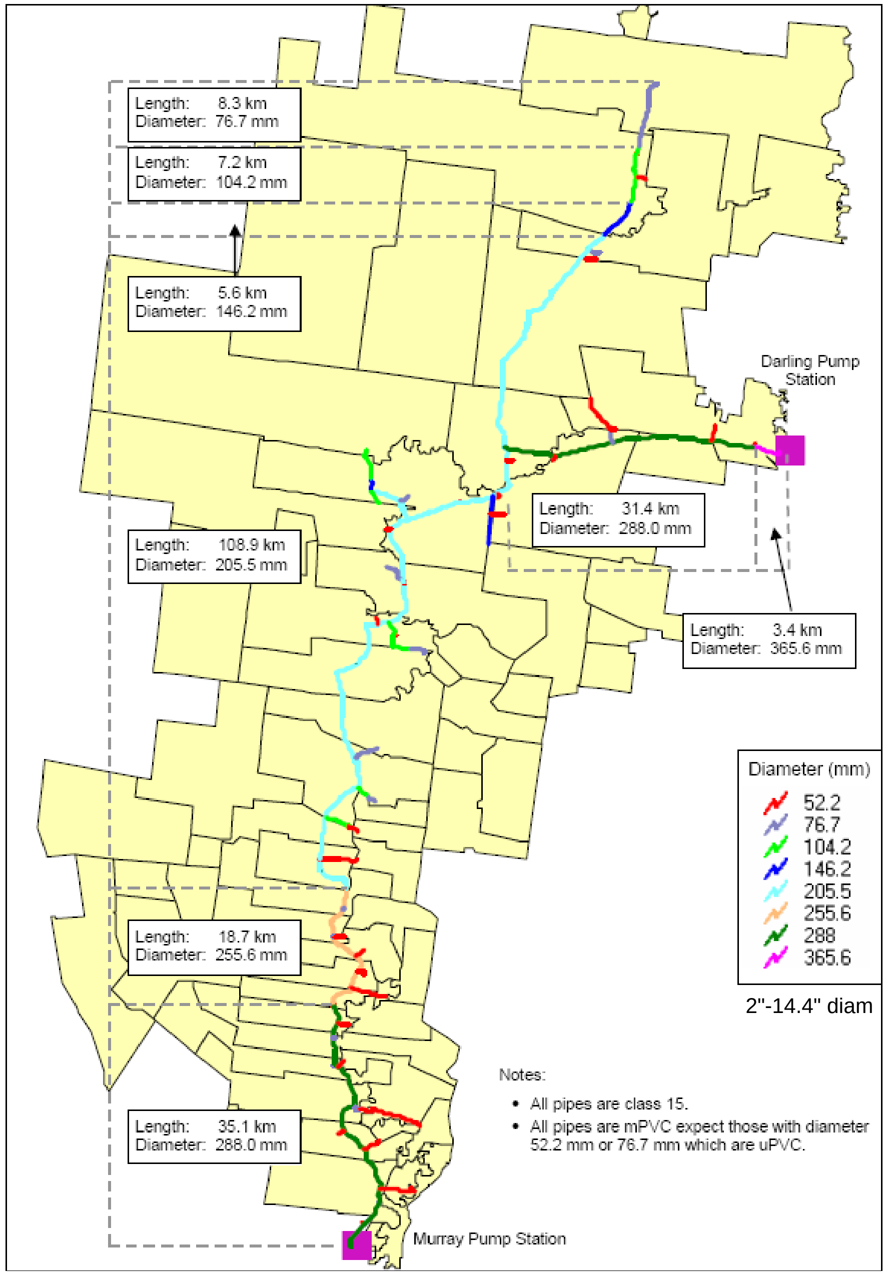

Figure 1. Darling-Anabranch Water System showing a near-optimal solution for one of nine different scenarios investigated. The different optimized solutions produced by the OGA allowed the Client to see the full consequences, in terms of capital and operating costs and performance, of the different options they wanted to consider.

pressure reducing valves to serve a major spur area.

Original versus Optimized Solutions

The original Anabranch solution developed by Commerce was taken as the baseline solution. The baseline solution was first compared to the Scenario 1 optimized solution which met the same criteria. A 16% savings in life-cycle costs was achieved by the Scenario 1 solution, which certainly caught the Client's attention.

The optimized solutions for all nine scenarios were compared and contrasted so the Client could decide which design would best suit their needs. Total costs did not vary greatly from one design scenario to the next but there were some differences in the balance between capital and operating costs in the solutions. Overall life-cycle cost savings for the nine scenarios ranged from 12% to 18%.

Conclusions

Applying OGA optimization to the Darling Anabranch Pipeline design problem proved to be highly advantageous for the Client. Once the OGA problem was formulated, it was a simple matter to revise the OGA setup to investigate a wide range of design scenarios and decision variables. For each optimized design, the OGA directly computed its capital cost and lifetime operating cost.

The Client could immediately see differences among the scenarios in terms of the project hydraulics and project finances. The Client also investigated a wide range of solutions so was able to make an informed decision, rather than just proceeding with its original plan. Finally, since the OGA was totally unbiased in optimizing each distinct scenario, the Client could be confident in the final outcome.

The final OGA runs produced a system design that was 18% less costly than the original baseline design. Equally important though was the fact that the Client was able to work closely with Optimatics throughout the study to gain a clear understanding of how cost savings could be achieved. Only acceptable revisions to the solution were allowed so the final design fully met the Client's needs. The optimized design is now out for bid.

GA Optimization Advances Since 1995

Water system optimization has advanced in various areas since Optimatics first proved its genetic algorithm (GA) pipe network technology. In 1995, our fledgling GA software successfully improved on Fort Collins-Loveland Water District's newly recommended 2015 Master Plan while meeting the same design and performance criteria. The GA identified an optimized plan with better distribution of flows and pressures, significantly less new pipe, and capital cost savings of 49% compared to the original plan.

Optimize Project Life-Cycle and Aging Water Mains

In the past 11 years, dozens of water utilities have proceeded with similar GA optimization studies to identify the best mix of allowable pipe, tank, pump and regulator location and size options to meet their water master plan and capital improvement program objectives. For Grand Prairie, Texas, City of Toronto /Region of York and later GA master plans, project life-cycle costs were minimized to achieve an optimal balance between future capital and operating costs.

The next significant application that Optimatics addressed was optimizing rehabilitation and replacement of aging water mains with San Diego Water. The AWWA Journal article by Leonard Wilson, et al (voted 2005 Best Paper Award for the Distribution & Plant Operations Division) cited estimated cost savings of 36% (nearly $20 million) for mains R&R in the Alvarado Water Treatment Plant area compared to SDW's original solution.

The Alvarado WTP area mains R&R study also spawned the concept of optimizing system redundancy to enhance reliability with "automatic back-up" in the case of critical main breaks or source outages. The GA formulation required the optimized solutions to not only meet the basic demand condition but also to maintain supplies at full pressure for each of 20 emergency outage conditions—resulting in highly redundant, near minimum-cost solutions.

Operations and Water Quality GAs

Since 2004, Optimatics has advanced its GA capabilities into the areas of system operations and water quality optimization. We developed a customized GA tool for Yarra Valley Water (Melbourne, Australia) to optimize pump operations that YVW operators can use on a daily basis to update operating plans. We also optimized operations for the Summit WTP (operated by United Utilities Australia) raw water and treated water pump stations. Early results indicate operating cost savings on the order of 30% compared to current operations.

Since 2005, Optimatics has been working with Las Vegas Valley Water District to develop a new GA optimization tool to improve system water quality. The GA tool aims to limit water age in critical areas, while at the same time minimizing system-wide operating costs. The GA tool is coupled with a state-of-art distributed computation technology to speed optimization run times by as much as 100 times. In the future, District staff may use this tool to optimize their daily operational plans for reducing overall operating costs while maintaining water quality throughout the system.

Where to next? Optimatics plans to advance our water quality optimization capabilities so that we can help utilities' improve water age, contaminant and DBP levels. The results of our latest work will be available soon.

For information, contact Optimatics, 6535 N. Olmsted Ave., Suite 200, Chicago, IL 60631 • Phone (773) 792-2661 • Fax (773) 792-2677 • E-mail: info-us@optimatics.com • You can download past newsletter copies at *www.optimatics.com*.

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OPTIMATICS

The Optimatics Letter
c/o Optimatics LLC
6535 N. Olmsted Ave., Suite 200
Chicago, IL 60631-1414
www.optimatics.com

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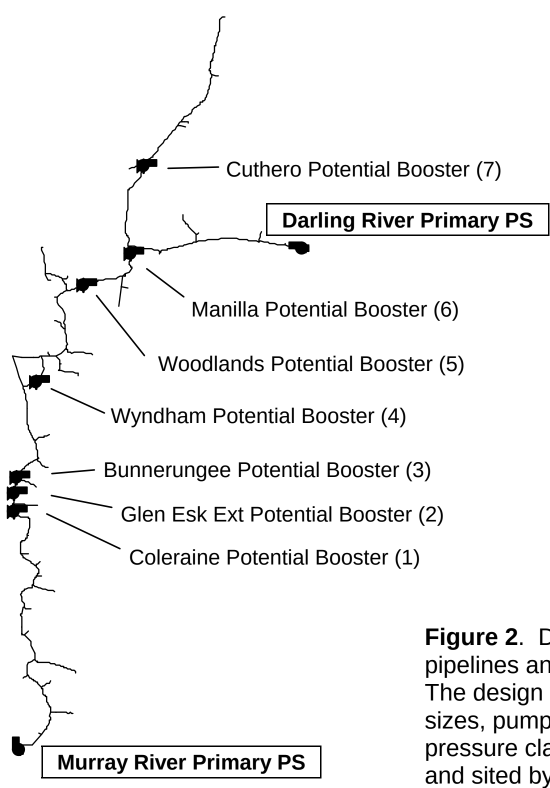

Figure 2. Darling Anabranch Water System transmission pipelines and spurs were designed using OGA optimization. The design variables included pump station locations, pump sizes, pumping heads, and pipe materials, diameters and pressure class. Up to two booster pump stations were sized and sited by the OGA from among seven locations.