The Optimatics Letter

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Optimizing Pipes & Pumps for a Concept Design

Much of the recent work in applying formal optimization techniques to distribution system problems has focused on detailed design. Applying optimization at the conceptual design stage is another powerful application for this new technology.

In concept design, decisions need to be made about the overall layout of the system, and the locations of tanks and pump stations. Decisions made at this stage will likely have a tremendous impact on the final capital and operating costs of the system. While reasonable decisions can be made based on experience and judgment, the use of a formal optimization technique can allow rapid evaluation of a huge number of alternatives quickly leading to the identification of the best design concept.

Northern Mallee Pipeline Project

We recently applied the Optimatics Genetic Algorithm (OGA) to minimize capital costs and pumping costs for a grand water supply scheme in rural Victoria, Australia. For decades, the Wimmera Mallee Domestic and Stock Supply System has supplied water via 10,000 mi of channels to 51 towns and 25,000 farms spread across 11,600 mi^2.

To mitigate rising groundwater tables and increasing salinity levels, Wimmera Mallee Water (WMW) is constructing pressure pipe networks to supply water from new pump stations on the River Murray to the Northern Mallee. Five sub-systems have been completed with over 800 miles of pipe installed, and six pump stations and four elevated tanks constructed.

The western half of the Northern Mallee Pipeline Project is now underway as shown in Figure 1 (on the back page). Water will be pumped from the River Murray at Wemen about 30 miles south to an existing earthen storage at the town of Ouyen. From there, the water will be distributed through an extensively looped pipe network to supply more than 1,200 dryland farms and seven rural towns.

OGA Approach to the Concept Design

WMW decided to apply OGA optimization to help develop the overall supply concept prior to proceeding with detailed design. WMW's objective was to optimize key supply concept parameters, including the capacity and location of booster and relift pump stations, and the volumes, locations and benefits of elevated and ground storage tanks. WMW did not require final pipe sizes, but it was necessary to select realistic pipe sizes for each supply concept since pipe costs amounted to more than 90% of system life cycle costs.

WMW had estimated water demand requirements for the towns and farms in the area as shown in Figure 2. The town demands were assigned to the existing town storages, while the farm demands were grouped and assigned to 180 demand nodes. Based on topography, the project area could be conveniently divided into three separate sub-systems (see Figure 1).

(Continued on page 2)

This OGA case study quickly identified the best concept design option leading to life cycle cost savings of more than 20%

Optimization Catching On in Water Industry

At the IMTech Conference in New Orleans we were asked why water utilities and consultants are not doing more with optimization. Actually, there is quite a lot happening in the field as evidenced by the great line-up of papers being presented at the Water Distribution System Analysis Mini-Symposium at ASCE's June 6-9 conference in Tempe, Arizona. The papers include:

- *Leak Detection and Calibration of Water Distribution Systems using Transients and Genetic Algorithms*
- *Sampling Design for System Calibration using Genetic Algorithms*
- *Parallel Computing in Water Network Analysis and Optimization Processes*
- *The Uncertainty of Demand in Water Supply Optimization Models*
- *An Optimal Neural Network Model for Daily Water Demand Forecasting*
- *Optimal Supervision of Drinking Water Distribution Network*
- *Application of Simulated Annealing to Optimal Operation of Water Systems*
- *Reliability-Constrained Optimal Design of Water Distribution Networks Using Connectivity and Genetic Algorithms*

Published jointly by Frey Water Engineering, Inc., USA and Optimatics Pty Ltd, Australia, consultants specializing in OGA optimization.

An OGA optimization analysis was then formulated to compare five different water supply concept design options for a given "typical" network layout (Figure 1). For each concept design option, the OGA quickly optimized (1) pump station pump heads, (2) the normal operating water level of any elevated tanks, and (3) preliminary pipe sizes and pipe pressure classes over a series of OGA runs.

The resulting optimized concept designs could then be compared on an equal basis since each represented a near-optimal combination of pipes and pump choices that minimized overall life cycle costs. In total, more than 25 million individual solution evaluations were made to optimize the five initial concept designs. Each OGA run selected diameters for 245 pipe sections from 8 pipe size choices for a given pump head, resulting in a solution space of about 10^{221} possible solutions.

Initial and Final Concept Designs

WMW's five initial concept design options:

Option 1 (Base Case): The entire area is supplied from a single pump station (PS) at Ouyen's town storage.

Option 2: Ouyen PS supplies the Ouyen and Walpeup sub-systems and Tempy town storage; a relift PS at the Tempy storage supplies Tempy sub-system.

Option 3: Ouyen PS supplies the Walpeup and Tempy town storages; relift PSs at those town storages supply the Walpeup and Tempy sub-systems.

Option 3a: Two in-line booster PSs pump water from Ouyen directly into the Walpeup and Tempy sub-systems without storing it first in the town storages.

Option 3b: Same as Option 3, except the relift PS at Walpeup pumps into an elevated tank from which the Walpeup sub-system is supplied.

After the five initial concept designs were evaluated, WMW selected a preferred concept design to be further optimized. The best of the initial designs, Option 3a, was revised to allow for rehabilitation of Underbool's existing earthen town storage, rather than replacing it with a ground storage tank as was assumed in all of the initial designs.

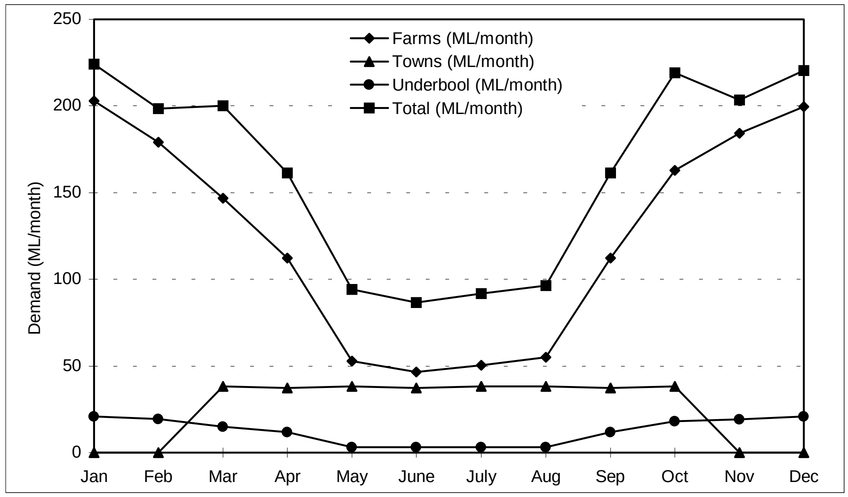


Figure 2. Average monthly demands (3 days storage at Underbool) (1ML=0.264MG)

Option	New pump stations (design flow in L/s, design head in meters)	Est. system life cycle costs ($ million)	PV of pumping costs as % of life cycle costs	% savings vs. Base Case Option 1
1	Ouyen source (83.6, 84.5)	A$23.767 (US$14.26)	5.3%	--
2	Ouyen source (84.0, 64.5) Tempy relift (35.8, 72.0)	A$20.672 (US$12.40)	6.9%	13.0%
3	Ouyen source (83.2, 74.5) Walpeup relift (19.4, 28.0) Tempy relift (35.8, 72.0)	A$19.794 (US$11.88)	8.2%	16.7%
3a	Ouyen source (83.6, 54.5) Walpeup booster (19.4, 50.0) Tempy booster (35.8, 75.0)	A$19.058 (US$11.43)	7.7%	19.8%
3b	Ouyen source (83.2, 74.5) Walpeup relift (19.4, 28.6) Tempy relift (35.8, 72.0)	A$20.033 (US$12.02)	8.1%	15.7%
4	Ouyen source (83.6, 54.5) Walpeup booster (19.4, 50.0) Tempy booster (35.8, 75.0)	A$18.334 (US$11.00)	7.7%	22.9%

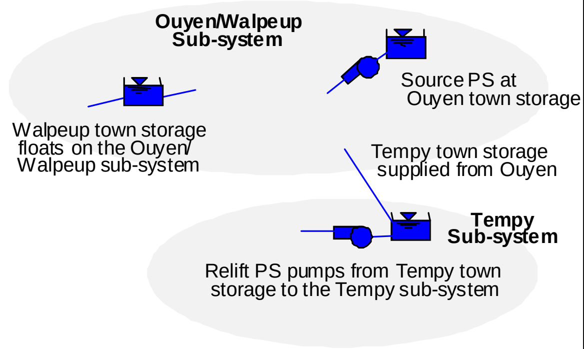
Table 1. Cost comparisons among the six optimized concept designs.

Study Results & Conclusions

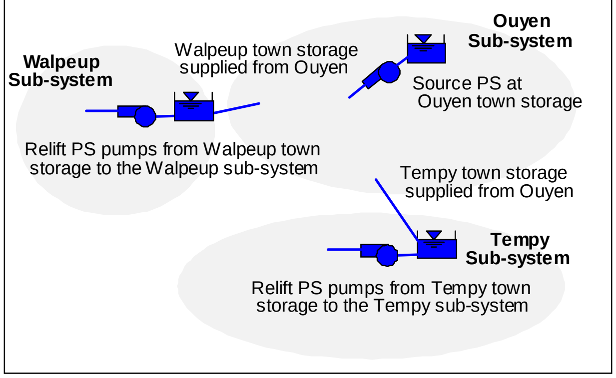
Table 1 summarizes the results of the OGA concept design review. It shows clearly that Option 3a is the best of the initial concept desig with savings of US$2.8 million (20%) compare to the Base Case design option.

This study demonstrates how the OGA can be used to very quickly generate optimized solutions for any number of options (whether design or operations). The preferred option can then be selected with plenty of confidence, and a more detailed analysis carried out to finalize the design.

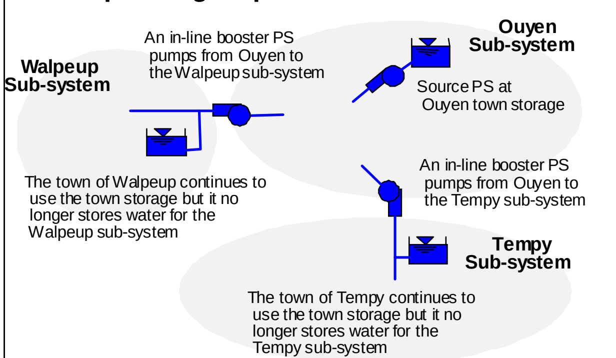
Concept Design Option 2



Concept Design Option 3



Concept Design Option 3a & 4



Simulation Modeling Challenge Update

We continue to receive excellent solutions to the Modeling Challenge, as well as some interesting commentary. **Martin Dix**, an expert modeler with **Boyle Engineering Corporation** in Newport Beach, CA, recently submitted three solutions to the problem. Martin first tried adding 6 parallel pipes to the existing network; although feasible, the capital cost of the solution was not great. He then submitted an 8-pipe solution that was only slightly lower in cost than his first. On his third try, Martin came up with an excellent mix of sizes for his original 6-pipe solution, dropping the capital cost of the solution nearly $400,000 and moving Martin (temporarily) into first place.

We particularly enjoyed the comments that Martin sent along with his third solution:

> *"I see what you mean. I keep finding better and better solutions. I'm spending too much time on this. This will be my final solution. The challenge was very fun and educational. The next time I try to optimize a new system, I will give Frey a call."*

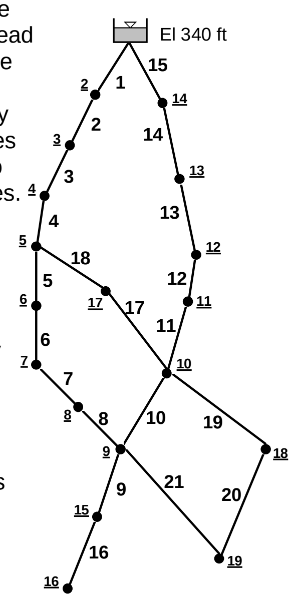
Other Notable Entries and Our Current Leaders

Terry Hui, a modeler at the **Greater Vancouver Regional District**, submitted an 8-pipe and then a 7-pipe solution that very nearly took the lead. **Tom Bean**, District Manager for **Pitometer Associates**, spent some down-time at the Texas Section AWWA conference in Fort Worth to develop a great 7-pipe solution.

By the end of April, however, we surprisingly had a tie for the lowest cost solution. **Reginald Soenen** from **Belgium** was first to submit a very efficient 6-pipe solution. Some weeks later, **Angela Hoover**, a modeler for **Harford County Water & Sewer** in Maryland, came up with a nearly identical 6-pipe solution that just happened to have the exact same cost.

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***. 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. There are 11^{21} possible combinations, so finding the best solution could involve a bit of luck.



All entries are due by July 4, 1999. In the case of a tie, the earliest lowest cost entry received will be awarded the full $500 cash prize. The hydraulic feasibility of each solution will be checked in EPANET. The upgraded layout must supply the specified demands with pressures not less than 40.00 psi at Nodes 2-19. In July, we will report the winning simulation design and compare it to one or more OGA optimized solutions.

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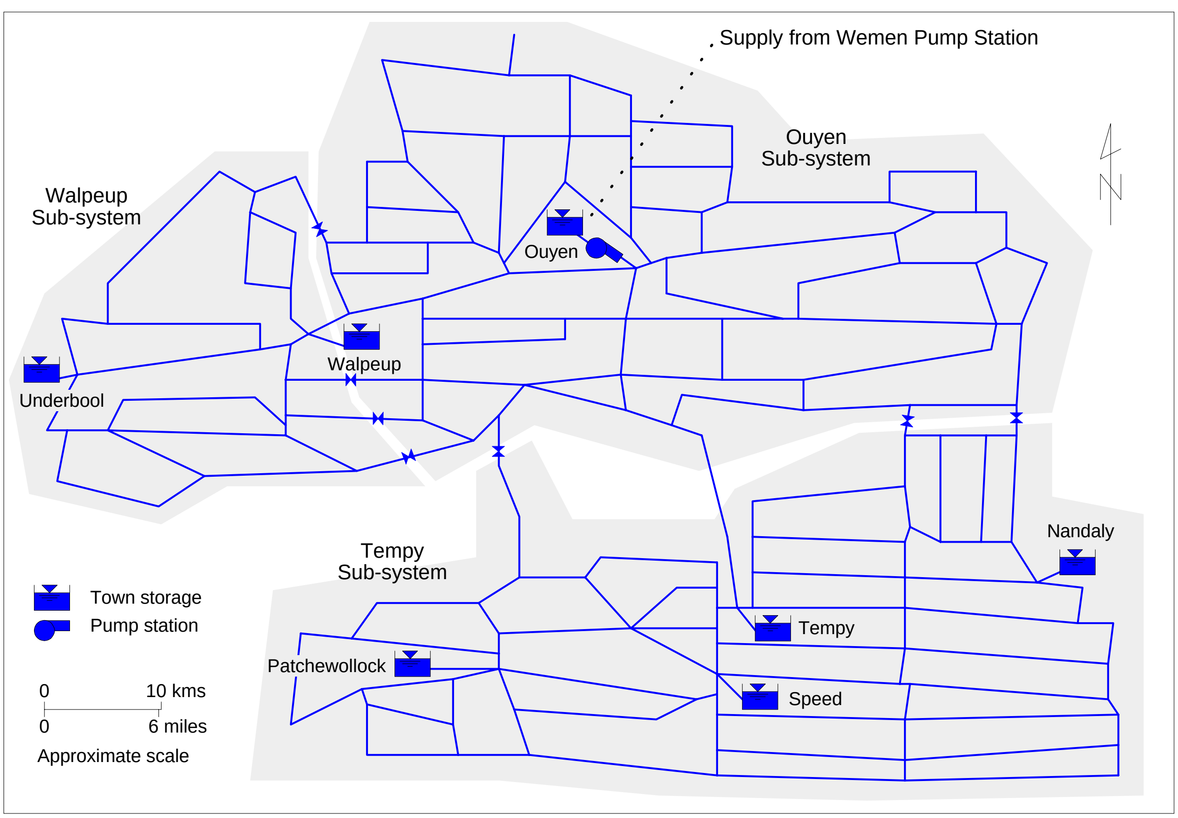

Figure 1. Northern Mallee Pipeline Project layout (western half) showing the three sub-systems. Pressure pipe network with 245 pipes, 930 miles in length. A total of 180 demand nodes represent 1200+ farms and seven rural town storages.