OPTIMAL PLANNING FOR THE GOLD COAST POTABLE WATER DISTRIBUTION SYSTEM

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ABSTRACT

Gold Coast Water is continually reviewing and updating the master planning strategy for the Gold Coast water distribution system. The aim is to identify the best combination of new infrastructure to satisfy both the rapidly increasing demands on the system for the local area, while supporting the new infrastructure being proposed as part of the wider South East Queensland water grid.

As part of this review process Gold Coast Water maintains a Priority Infrastructure Plan (PIP). This medium to long-term infrastructure development plan is developed in-house by Gold Coast Water modellers using traditional design approaches.

In recognizing the difficulty of using traditional design methods to develop a minimum cost PIP, Gold Coast Water and Optimatics undertook a Genetic Algorithm (GA) optimisation study of the PIP.

This paper discusses the process undertaken in applying a formal optimisation framework to significantly improve both performance and cost of the Gold Coast Water PIP. A comparison of results is made with the original PIP demonstrating the effectiveness of the methodology and technology applied.

KEYWORDS

Infrastructure planning, master planning, water network modelling, genetic algorithm optimisation.

1 INTRODUCTION

The management of water resources in South East Queensland is more important than ever, given the dry conditions experienced in recent years and the pressures of population growth in this rapidly growing area.

A South East Queensland water grid is currently being implemented to provide water to the areas of South East Queensland that need it most. As part of this initiative, a desalination plant at Tugun and a large diameter transmission main traversing the Gold Coast water distribution system to connect the desalination plant to other South East Queensland areas has been construction.

Gold Coast Water (GCW) and Optimatics recently completed a series of projects to develop a 50-year master plan for the northern and central water supply districts of the Gold Coast water distribution system. The aim of the projects is to identify the best combination of new infrastructure to satisfy both the rapidly increasing demands on the system for the local area, while supporting new infrastructure being introduced as part of the wider South East Queensland water grid including the Tugun desalination plant and the Southern Regional Water Pipeline (SRWP). Genetic Algorithm optimisation was used to assist in the development of the Master Plans.

2 SYSTEM OVERVIEW

2.1 GOLD COAST WATER DISTRIBUTION SYSTEM

The studies undertaken aim to identify optimal augmentation options for future water supply to the five Gold Coast northern water supply districts of Gaven, Helensvale, Pimpama, Stapylton/Ormeau and Beenleigh and the three central water supply districts of Southport West, Molendinar and Nerang.

The northern and central water supply districts are supplied from the Molendinar Water Purification Plant (WPP). The Molendinar WPP complex includes the purification plant, the clearwater tank and pumps and a number of distribution reservoirs. Molendinar WPP receives water from the Hinze Dam and the Tugun desalination plant. Figure 1 is a schematic showing detail of the changes to the configuration of the Molendinar WPP complex.

Water is currently pumped from Molendinar WPP to the northern water supply districts via existing Gold Coast transmission mains. The central water supply districts are supplied from Molendinar WPP by gravity. An important aspect of this work was the accurate modelling of the existing and future operation of the Molendinar WPP. In addition, the GA optimisation was used to evaluate proposed augmentations within the Molendinar WPP complex.

The hydraulic models used in this study considered production at Molendinar WPP as well as flows to and from the plant from the northern and southern systems (including mixed dam water and desalinated water flows via the Southern Regional Water Pipeline) to more accurately model operation of the plant and water levels in the Molendinar Reservoirs.

2.2 SOUTHERN REGIONAL WATER PIPELINE

The Southern Regional Water Pipeline (SRWP) is a large diameter transmission main traversing the Gold Coast water distribution system that connects the Molendinar WPP and Tugun desalination plant to the South East Queensland water grid.

In the short term, it is proposed that the SRWP will be a dedicated pipeline transferring water from the Molendinar WPP to the South East Queensland (SEQ) connection. A new pump station at the Molendinar WPP will pump water north from the WPP. A new booster pump station at Coomera will boost to the Stapylton balance tank. The water will then flow by gravity to the SEQ connection.

In the long term, it is anticipated that less water will be transferred from the Stapylton balance tank to the SEQ connection. The remaining capacity in the SRWP will be used to help meet future demands in the Gold Coast northern system. Three offtakes are proposed between Molendinar WPP and the Stapylton balance tank at Helensvale (contingency offtake), Pimpama and Ormeau at which water will be supplied to the reservoirs of the Gold Coast northern system.

The GA optimisation was used in this study to determine future flows to the Gold Coast northern system at the SRWP offtakes and to investigate how system operation changes due to the SRWP. Figure 2 is a schematic showing how the SRWP is integrated into the Gold Coast northern system.

3 GENETIC ALGORITHM OPTIMISATION

The application of Genetic Algorithms (GAs) to the optimisation of pipe networks was first considered and carried out by researchers at the University of Adelaide in the early 1990's (Simpson et al., 1994; Dandy et al., 1996).

GA optimisation is a directed search technique that evaluates hundreds of thousands of possible solutions as it converges on the best solution alternatives. In applying this artificial intelligence algorithm, the GA was linked to extended period simulation hydraulic models of the northern and central systems.

The GA optimisation approach contrasts with traditional simulation analysis where the designer uses trial-and-error, engineering judgment and experience to evaluate a handful of candidate solutions. Although a hydraulically feasible solution can usually be found, it is very likely the cost of the resulting design is much higher than it needs to be.

Through applying the GA optimisation approach, the cost of required augmentations for the northern and central systems was reduced significantly. The application of the GA also led to recommendations regarding future system operation. The GA study identified a final design and provided much needed feedback throughout the study for strategic decision making.

Figure 1: Proposed Future Configuration of the Molendinar Water Purification Plant Complex

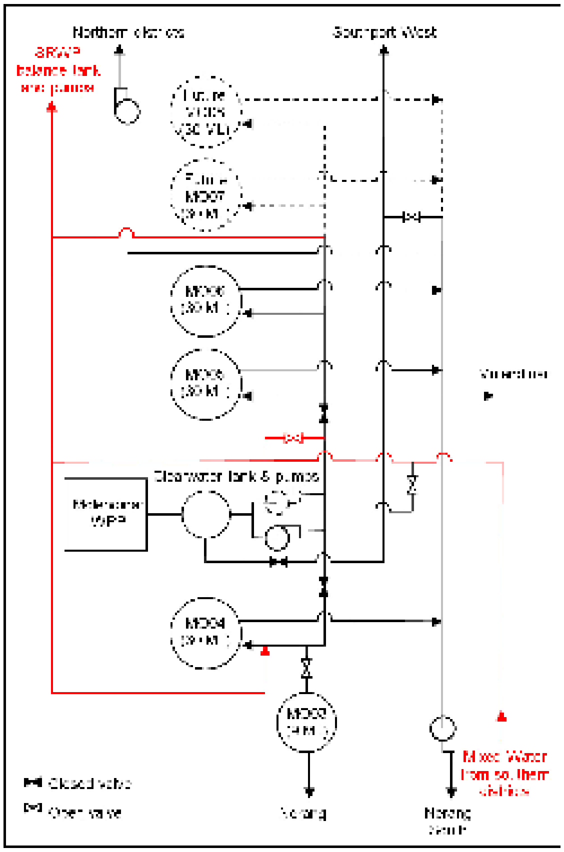
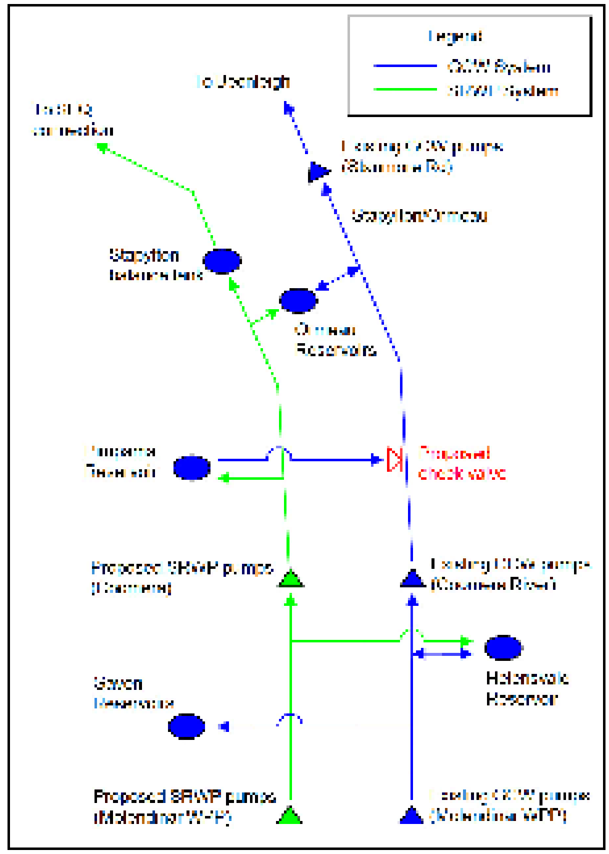


Figure 2: Integration of the Southern Regional Water Pipeline into the Gold Coast Northern System



4 FORMULATING THE OPTIMISATION PROBLEM

In general, an optimisation problem can be expressed in the following way: *Find the set of values for the decision variables that minimise (or maximise) the objective function value subject to a set of constraints.*

4.1 DECISION VARIABLES

GCW identified several design options for the augmentation strategy that were considered by the GA optimisation. Specifically, the GA optimisation model was formulated to determine a near-optimal combination of the following design options:

- Diameters of trunk and reticulation mains 100 mm diameter and above
- Capacities of new pump stations and capacity expansions of existing stations
- Volumes of new storage tanks required
- Pump station operating schedules
- Settings for regulating valves including flow settings for control valves at SRWP offtakes
- Future operating strategies for the Molendinar WPP

4.2 OBJECTIVE FUNCTION

The objective of the optimisation is to identify a low cost combination of future system augmentations that can be operated efficiently in conjunction with existing and proposed future system facilities. The proposed augmentations must also satisfy specified levels of system performance subject to future demand conditions.

Unit costs for new pipe, new tanks and reservoirs (steel elevated tanks, concrete elevated tanks and ground-level reservoirs) and new pump stations were provided by GCW. The GA optimisation was formulated to minimise life-cycle costs including capital costs and ongoing system operating costs.

4.3 DEMAND CONDITIONS

The optimisation model was formulated to consider the future system subject to forecast Planning Scheme Demand (PSD) conditions (year 2056 demands at the time of this study).

The optimised system was required to satisfy specified levels of performance while supplying 3 consecutive PSD maximum days. Total system demand on the PSD maximum day was anticipated to be approximately 225 ML/day for the northern districts and 207 ML/day for the central districts.

The optimised system was also required to satisfy specified levels of performance while subject to a series of fire fighting demand cases. A total of 85 residential and commercial/industrial fire fighting scenarios were considered for the northern system including 56 fire locations specified by GCW and an additional 29 fire locations at the extremities of proposed pipe augmentations. About 45 residential fire fighting scenarios were considered for the central system.

4.4 SYSTEM PERFORMANCE CRITERIA

The GA optimisation was formulated such that proposed augmentations enable the system to meet specified levels of system performance. The system performance criteria were derived primarily from GCW's Desired Standards of Service.

Specified levels of performance for the Gold Coast system subject to three consecutive maximum days included:

- Minimum allowable pressure 22 m
- Maximum allowable pressure 80 m
- Maximum allowable velocity 2.5 m/s
- Minimum reservoir levels 15%

The tanks and reservoirs are designed to balance subject to mean day maximum month demands and therefore water levels may fall during a maximum day. However, water levels may not fall below 15% for 3 consecutive maximum days. Tanks and reservoirs were assumed to start 75% full.

The GA optimisation also considered provisions for firefighting demand cases, including minimum allowable pressures for fires of specified duration at residential, high density residential (greater than 3 stories) and commercial/industrial buildings. The background demand considered was the maximum hour.

4.5 DISTRICT METERED AREAS (DMAS)

The hydraulic model was updated to include all of the existing and currently proposed DMAs within the water supply districts including augmentations implemented and changes to system configuration (supply feeds and valves closed to isolate the DMA).

4.6 PRESSURE ZONE BOUNDARIES

The GA optimisation was also used to investigate the possibility of shifting the Molendinar/Southport West pressure zone boundary in future years.

4.7 STAGING OF AUGMENTATIONS

Once the ultimate system was established, the staging of proposed augmentations was considered by modelling the system subject to existing demand conditions, and anticipated 2011, 2016 and 2021 demand conditions and supply assumptions. The hydraulic models were used to determine when the future augmentations that were proposed for the ultimate PSD (2056) system would be required.

The optimisation of the system subject to existing demands was required to determine any immediate improvements that may be necessary.

5 GA OPTIMISATION APPROACH

GA studies such as these are typically carried out in a number of stages.

5.1 ESTABLISH THE DESIGN DATA

The first step is to establish improvement options for facilities, cost functions, system performance criteria and design constraints. This type of information is no different from that required to design the system using the traditional approach. A hydraulic model of the system subject to the future demand conditions to be considered is built. All of the potential system improvements are added to the model (potential future pipes, pumps, tanks, etc. are initially added to the model with dummy sizes and capacities).

5.2 FORMULATE THE OPTIMISATION PROBLEM

The optimisation problem is set-up using the GA optimisation software, *Optimizer WDS*. The formulation includes:

- Costs for new facilities (such as unit costs for supply and install of new pipe)
- Ranges of sizes and capacities to consider for proposed future improvements
- Functions to estimate ongoing costs (such as pump operating costs and water production costs)
- Operational options for new and existing facilities (such as ranges of allowable settings for regulating valves)
- System performance criteria and parameters for penalty functions used to penalise solutions that do not meet the constraints

5.3 PRELIMINARY OPTIMISATION RUNS

Preliminary GA optimisation runs are carried out. At this point, errors in the hydraulic model and deficiencies in the system (such as areas of low pressure or reservoirs that are difficult to refill or exercise) are quickly identified.

The ‘raw’ solutions identified by the GA may require some manual refinement to ensure a solution that is practical and meets all the constraints.

5.4 REVIEW OPTIMISATION RESULTS

One or more solutions developed are presented for review (in the form of hydraulic models, schematics, costing spreadsheets and curves showing system operation). Additional improvement options may need to be developed to address system deficiencies. Operational issues are identified and options developed to overcome these. Undesirable aspects of the solution are identified.

5.5 ITERATE OPTIMISATION RUNS

The GA optimisation formulation is modified as a result of the client review and new optimisation runs are carried out. The number of iterations of GA optimisation runs and client reviews required will usually depend on the complexity of the system under consideration.

6 KEY DIFFERENCES BETWEEN OPTIMISATION STUDY AND 2006 PIP

GCW maintains a Priority Infrastructure Plan (PIP), a medium to long-term infrastructure development plan. The PIP is developed in-house by GCW modellers using traditional design approaches. The proposed GA system augmentations are compared with the augmentations recommended by the 2006 PIP. The comparisons are made to assist GCW planning staff in their evaluation of proposed GA system augmentations.

The major differences between the 2006 PIP and the GA-optimised system operational philosophy are summarised in Table 1. The 2006 PIP had not considered the future system subject to fire fighting demand cases. In addition, the PIP did not consider changes to system configuration and augmentations implemented to introduce DMAs to the Gold Coast central and northern water supply districts.

Table 1: Comparison between the PIP and GA Operational Philosophy

Operational Philosophy / System Configuration	PIP	GA
Sources of supply	Molendinar WPP and Logan connection	Molendinar WPP sole source of supply
Fire provisions	Not considered	More than 100 residential and industrial/commercial fire fighting locations considered
District Metered Areas	Not considered	DMAs considered including system augmentations implemented and changes to system configuration

Furthermore, the 2006 PIP operational philosophy was significantly different from the current and likely future operational philosophy of the system and that considered by the GA in that the PIP model considered supply from the Logan connection in the far north of the northern system. The GA did not consider any supply from Logan and a number of new mains proposed by the GA are required to transfer water to the northernmost water supply districts. The water supplied to the water supply districts in the far north by the GA optimised system must originate from Molendinar WPP in the south of the northern system.

7 GA OPTIMISATION RESULTS

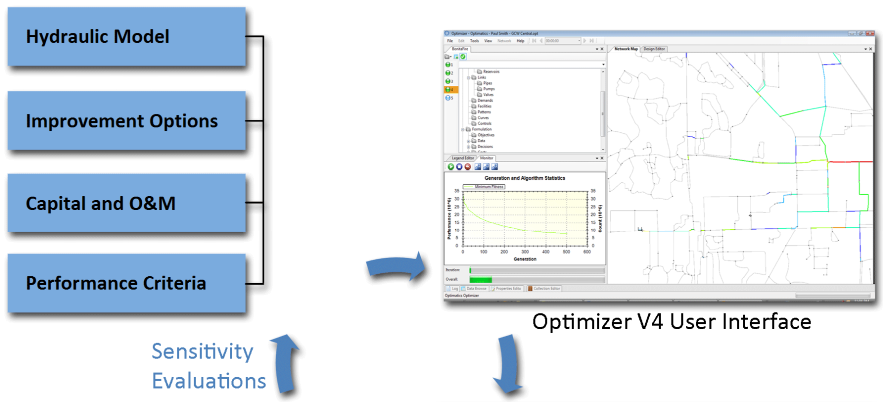
A series of GA optimisation runs were carried out on the Gold Coast northern and central systems and several alternative solutions were identified and refined. The proposed GA-optimised system augmentations represented the best elements of several alternative solutions identified by the GA.

The GA-optimised system achieved significant cost savings compared to the recommendations of the 2006 PIP, however, the PIP and GA-optimised systems are based on different operational philosophies and so it becomes difficult to make a fair comparison.

The savings in the capital cost of proposed system augmentations was approximately 13% for the northern system and 31% for the central system. This is despite the additional costs that can be attributed to satisfying fire fighting requirements and the additional large diameter mains required to transfer water treated at Molendinar WPP to the northernmost water supply districts.

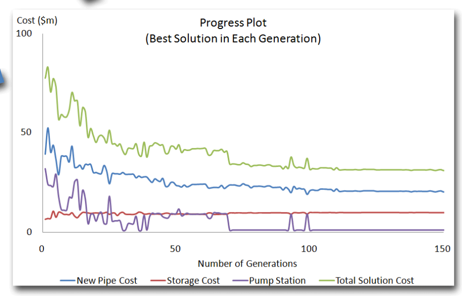
An overview of the iterative optimisation process is shown in Figure 3 together with a comparison between the capital costs for the PIP and optimised designs. The differences in operating costs between the two designs were negligible.

Figure 3: Iterative Optimisation Process with Results for the Gold Coast Central System



Comparison of Designs		
Improvement Category	**PIP Cost ($M)**	**Optimised Cost ($M)**
New Pipes	32.3	19.3
Pump Station	1.6	1.3
New Tanks / Reservoirs	10.7	10.1
Total Infrastructure Cost	**44.6**	**30.7**

Optimization Solution Cost Summary



Optimization Progress

8 CONCLUSIONS

The GA-optimised system achieved significant cost savings compared to the recommendations of the Gold Coast 2006 Priority Infrastructure Plan which was developed using a traditional approach (trial-and-error process using a simulation model). The cost savings were achieved despite the consideration of more than 100 fire fighting cases and a more stringent operational philosophy.

The GA optimisation studies identified both a final design for the entire northern and central system and provided information regarding the staging of proposed augmentations. In addition, much needed feedback was provided throughout the study for strategic decision making. The GA-optimised system considered the current and most likely future system configuration and operational philosophy. The GA optimisation studies made recommendations regarding existing and future system operation and identified a number of current and likely future system operational issues particularly related to integration of the Southern Regional Water Pipeline, operation of the Molendinar Water Purification Plant complex and shifting of pressure zone boundaries.

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REFERENCES

Dandy G. C., Simpson A. R. and Murphy L. J. (1996) 'An improved genetic algorithm for pipe network optimization' Water Resources Research, 32(2), 449-458.

Simpson A. R., Dandy G. C. and Murphy L. J. (1994) Genetic algorithms compared to other techniques for pipe optimization, Journal of Water Resources Planning and Management, ASCE, 120(4), 423-443.