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# Optimization of complex water supply network

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**Abstract**

The Millennium drought created critical water shortages throughout Australia and particularly in South East Queensland (SEQ). In response to this the bulk water network was significantly enhanced resulting in large infrastructure augmentations consisting of cross regional pipelines, a desalination plant and a purified recycled water plant. Given that SEQ can transition from drought to flood and vice versa in a short period of time it is a fine balance to operate the new more complicated asset base economically whilst maintaining sufficient supply security. With rising energy prices and the increasing cost of living pressures, there is an immediate need to better understand what optimal grid operation looks like and this is currently being investigated by the Seqwater Decision Support System (DSS).

Till now, a network such as the SEQ water grid with its variety of water supply sources of varying reliabilities and complexity of the network has been operated in a relatively manual manner using manual heuristics. Given the number of factors which need to be considered when making decisions about which parts of the network to activate at any one time and the limitations of the human mind to resolve these, means that sub optimal results are frequently generated.

The development of a DSS using optimization techniques can help determine the most efficient mode of delivery of water taking into account the operating costs of the various assets within the network, amongst a range of other constraints. This paper goes into detail the application of the optimization technology to the SEQ Water grid.



*Keywords:* Optimization; Water Network, Decision Support System, Supply Network Optimization

## 1. Introduction

The Millennium drought created critical water shortages throughout Australia and particularly in South East Queensland (SEQ). Water levels in SEQ dams reached combined levels of below 20% and saw SEQ residents reduce their average consumption to around 140 L/person/day. While consumption significantly dropped, the severity of the problem still remained necessitating more immediate and drastic responses to the situation.

A key response was the significant enhancement of the SEQ water grid resulting in large infrastructure augmentations consisting of cross regional pipelines, a desalination plant and a purified recycled water plant. The imple-

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mentation of the desalination plant and the purified recycled water plant provided climate resilient options for water supply although at a much higher cost to consumers. Given that SEQ can transition from drought to flood and vice versa in a short period of time it is a fine balance to operate the new more complicated asset base economically whilst maintaining sufficient supply security. With rising energy prices and the increasing cost of living pressures, there is an immediate need to better understand what optimal grid operation looks like. To get this broader understanding a Decision Support System (DSS) using optimization was developed to help better understand optimal operational modes of the integrated SEQ water grid.

This paper discusses the application of optimization techniques and the basis of the DSS which was developed for use by the operators and managers of the SEQ water grid

**Nomenclature**

| | |
|---|---|
| DSS | Decision Support System |
| SEQ | South East Queensland |
| MILP | Mixed Integer Linear Programming |
| WTP | Water Treatment Plant |
| SOP | System Operation Plan |

## 2. Optimization Overview

Before delving deeper into the application of optimization to the SEQ water grid it is important to understand the basis of optimization and the types of problems that this technology is being applied to currently. Optimization techniques have been used by scientists extensively in the past sixty years. Originally designed for military logistics, these techniques have spread widely into other areas of business including project planning, engineering design, transportation logistics, and financial analysis. Due to the advances in computational power and development in optimization algorithm, many industries have adopted this technology and implemented them in their decision making processes.

Network optimization problems are undoubtedly the most common type of optimization problems. This type of optimization is applicable to a wide range of industries which seek to determine aspects such as:

- Shortest path to solve distribution problems
- Transport scheduling
- Minimize travel time

Due to increasing demand to solve these types of problems there has been much focus in research to invent new techniques one of which is the Mixed Integer Linear Programming (MILP).

Mathematical programming, such as MILP has became one of the most widely explored methods for solving network problems mainly due to its rigorousness, flexibility and extensive modeling capability. MILP is well studied and considered to be an efficient algorithm able to be applied to many commercial applications.

Network optimization has more commonly been applied in the electricity industry. Specifically, in electricity distribution, the lack of storage in the system and high losses associated with power distribution has seen them as early adopters of optimization technology. Water distribution networks are not so dissimilar and certainly with the augmentation of the water grid, resulting in cross regional integration there is a need to have a better understanding of these assets and how they interrelate with the objective of reducing cost while maintaining water security

## 3. Optimizing Water Grid Network

As stated above the SEQ water grid was developed on the underlying principle that water for urban and industrial use in the SEQ region is a shared resource, to be managed by optimal conjunctive use of water sources within the region. As a result decision support system using optimization technology was conceived.

The SEQ Water Grid operates as a bulk potable water supply system that supplies water from a variety of supplies to several demand zones. The system is most simply explained as a number of nodal assets (dams, water treatment plants, dosing points, pump stations, etc), that are configured to allow a supply capability to deliver potable water to a demand zone (typically supplied to one or more reservoirs). These demand zones can either be connected with a number of differing variations or non-connected as part of the whole system. There are also specific constraints applied to subregional areas and the region in its entirety. Many of these are articulated within the System Operation Plan (SOP), System Operating Strategy and Market Rules. These represent a significant number of conditions and supporting variables requiring analysis to determine the optimal and preferred operation of the water grid.

Models are currently used as part of the decision process to validate a proposed option to inform the conditions to be applied. These models are discrete and used to prove a concept rather than validate a large number of potential scenarios and the multiple objectives that need to be considered. These models also do not currently assess many of the controls of cost and risk including reliability, water quality, risk and likelihood of risk occurrence. With this need in mind a decision support system using optimization technology was conceived.

Traditionally optimization in the water industry has focused on aspects such as pump scheduling and short term optimal distribution. However efficient management of water supply strategy for long term water security has widely been ignored. This is mainly due to the two well known facts, nonlinear hydraulic characteristics of water distribution networks and large sizes of real world network (large number of nodes, pumps, reservoirs etc). Due to these inherent complexity, scaling these mathematical models for long term water management (commonly looked at between 5 to 20 year time scale) becomes inapplicable for practical purposes. In addition to looking at optimal water delivery with cost and capacity constraints, the SEQ water grid is governed by a range of regional water management rules which is commonly implemented on network that covers wide regions (e.g. alternating supply from various regions depending on water levels).

The water grid is effectively a network optimization problem, meaning identifying the best way to transfer water from various sources to demand points by taking into account operational and cost constraints. In network operation, the constraints and objective functions are mostly nonlinear. But due to the associated difficulty in computer coding of nonlinear problems and other limitations, linear/non-linear programming optimization technique has not been widely used. Most approaches rather move towards implementing stochastic optimization such as genetic algorithm and simulated annealing. Stochastic optimization algorithms are very time consuming and depending on the complexity of the problem can take hours or days to solve.

The Water Grid Decision Support System addressed these challenges by coming up with an approach that provides a computationally tractable alternative which can rapidly evaluate a large range of options to previously. This was achieved by utilizing state-of-the-art and the highly researched MILP optimization algorithm. The challenges faced by large distributed water networks are similar; however there are also unique aspects that were implemented during the development of the decisions support system. In implementing the decision support system the aspects of the water grid that were considered in general and for long term operation included:

- Rainfall and inflow patterns
- Changing demand patterns
- Changing cost factors including increasing energy costs
- Varying operational capacity of desalination plant, water treatment plants and pipes
- Water security rules which are dependent on water storage levels
- Water quality requirements within the network and specification of mixing ratios between different sources

With this inbuilt constraints the DSS can be manipulated to operate in four distinct planning modes. These include:

- Water Security Mode

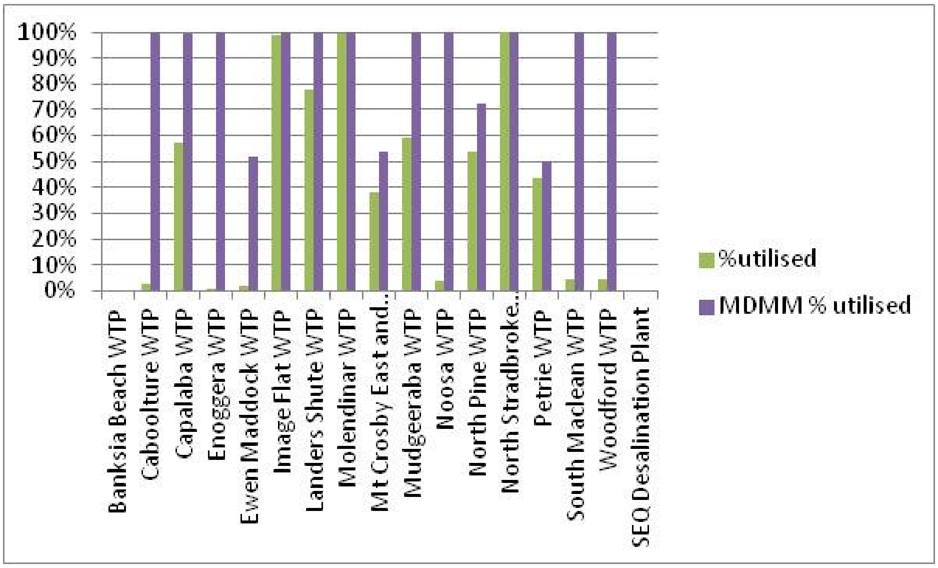


Fig. 1. Network Optimization of 20 year operation scenario.

- Capital planning
- Monthly Grid Instruction
- Contingency Planning

Operating under these modes allows the operator and mangers of the water grid to undertake:

- Evaluation of the effectiveness of the system operational strategy (ie the rules which govern the transfer of water between regions)
- What are cost effective modes of transferring water (ie which pipelines and treatment plants need to be used)
- Rapid assessment of the additional future infrastructure and the net present value of the various options (ie should we build a treatment plant at point X or upgrade a treatment plant at point Y)
- Operating the water grid under emergency planning scenarios (ie if pipeline X has failed what are the alternate efficient modes of delivery of water) The following section talks in more detail with practical examples of the various operational modes for operating the water grid.

### *3.1. Capital Planning*

The DSS can utilize 20 years of projected demands on a monthly time step thereby incorporating seasonal variation, assessment of asset utilization can be measured. The model can be run with one particular climate or weather pattern or with a stochastic or Monte Carlo analysis. In this particular case the 1902 drought period was utilized. With this model it was identified that even under these extreme circumstances, there were a number of smaller plants that were not utilized beyond their minimum capacity. Further investigation was undertaken to explore the impact of removing these plants and it was found that their removal could result in an operational saving of $ 4.5M (AUD). Fig 1 shows the output from the 20 year optimization which reveals the treatment plants that are not utilized or under utilized. Since the primary objective of the optimization engine is to meet the demand, the under utilization of the infrastructure demonstrates redundancy in the existing system. Fig 2 shows the output of 20 year optimization assuming a 50% increase in demand.

Using the output from the DSS as shown in Fig 1 and Fig 2 reveals:

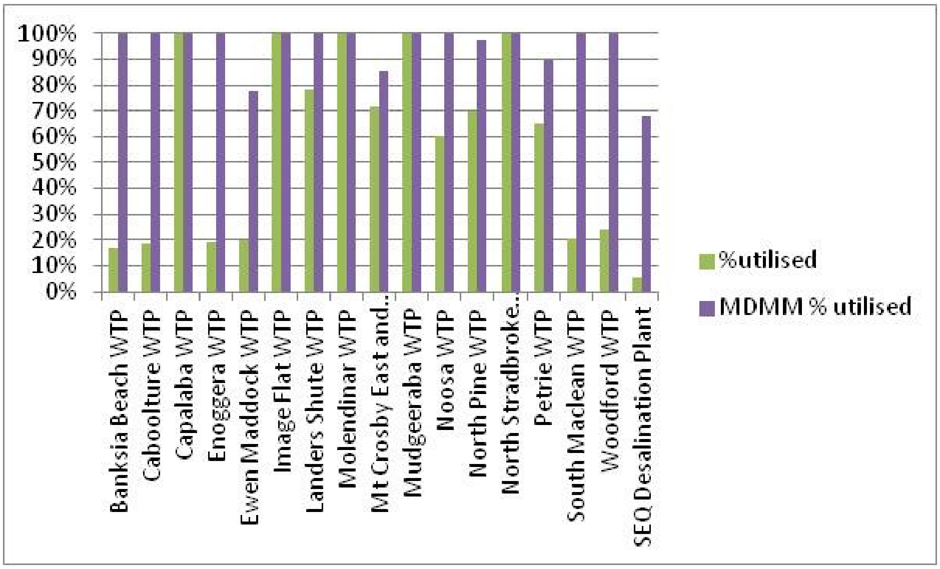


Fig. 2. Network Optimization of 20 year operation with 50% demand increase.

- Banksia Beach, Caboolture, Enoggera, Ewen Maddock, Noosa, South Maclean and Woodford WTPs can be switched off as even under a 50% increase in demand scenario these plants are under utilized;
- The NPV variable operational cost decreases by $4.5M over the full 20 year period but does not include fixed cost or capital savings

### 3.2. Water Security

The DSS has the ability to run over a large number of inflow sequences using a stochastic or Monte Carlo analysis. The inflow sequences were originally generated based on historical data and statistical variation. Whereas the current models test security using rigid rules and a basic grid network. The Decision Support System optimizes each inflow run to minimize operating cost and maximize security. The Decision Support System is still in early days of calibration, however it is envisaged that the model may find ways to operate the system that we have not thought of to date that may improve system yield. The difficulty will be when actually operating the system we will not know what inflows or drought scenario that we are in, however it is expected that as our demands approach the yield we will identify and utilize approaches that will improve our security and with the DSS we will be able to identify any increased operational costs to make an informed decision re security risk and cost.

In this example the Federation Drought has been used to assess security and is simply assessed by graphing Wivenhoe storage levels with and without the smaller water treatments plants. Given that Wivenhoe dam is the main SEQ water storage, failure to use other storages in the system could impact the levels within the main storage. However using the DSS and as shown in Fig 3, Wivenhoe storage level is relatively unaffected through the removal of the smaller plants.

### 3.3. Reliability

Reliability in a water grid network can essentially be defined as the systems ability to meet the demand even when random parts of the infrastructure become non-operational. If infrastructure stress is ignored in the decision making process, it may lead to result in some assets failing in their ability to meet demand a lot more frequently, needing alternate mechanisms of meeting the demand. At this point in time the DSS does not directly take into account the stress introduced on any particular piece of infrastructure when it is used it is used in earnest and is not an asset

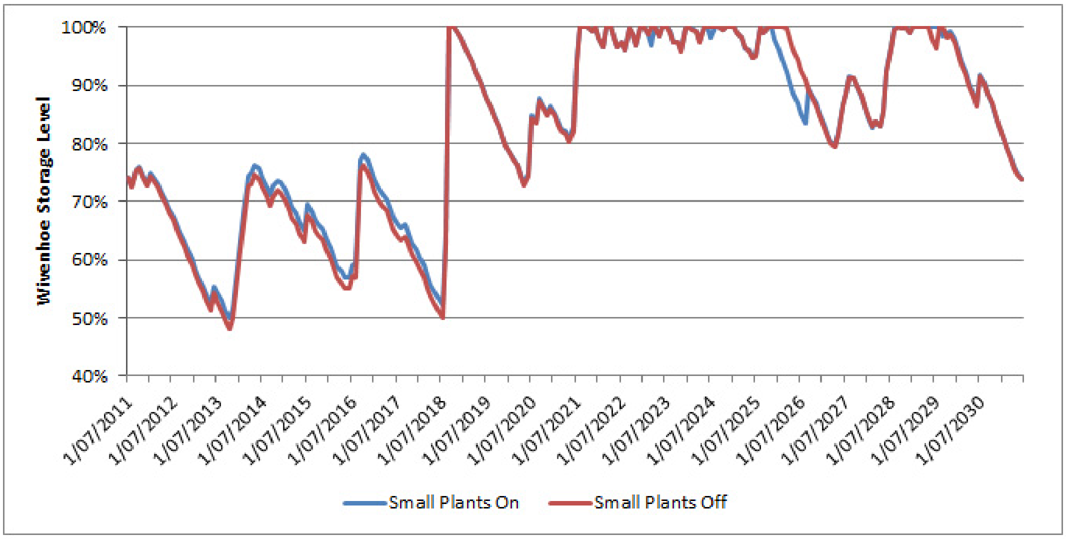


Fig. 3. Wivenhoe dam storage impact due to removal of smaller WTP.

management software as such. It however can consider the impact on reliability in an indirect manner ensuring that it is taken account of in the decision making process.

Using the example already discussed, when closing down six smaller plants there is a much higher burden on the larger plants and associated network infrastructure. To test the impact on reliability of the grid we can then assess this by reducing the capacity of the major plants by reducing the maximum rate of production until there is a failure to meet demand. This can not only assess the implications of long term capacity reductions but can also provide an understanding of what may happen if the plant was not able to produce water for any one month within the twenty year period. When the model was run with all six plants turned off and a major plant was assumed to not be able to supply water during a peak month it was shown that demand was almost satisfied indicating that with distribution and reticulation reservoirs supply would be maintained; in reality however it is unlikely that the plant would not be able to supply water for a full month during peak periods. The model in essence assists with determining how you need to change the operation of the scheme and how quickly an asset may need to be repaired or what storage may be required to maintain demands during a failure scenario.

Another example of capital planning and reliability assessment where it is currently being investigated on what impact there may be if a major plant such as the Desalination plant is isolated until required during a drought. To assess this, the DSS was manipulated to ensure that the desalination plant was only turned on when no other form of supply was available. The results showed that whilst everything was working to optimal capacity the desalination plant was not required until the next drought occurs. However when surrounding plants become reduced in their operational capacity, the results showed that the desalination plant would be brought on line as early as 2018-19 (Refer Figure 4). This information can then be utilized to assess operational modes for significant pieces of infrastructure such as the desalination plant or the purified recycle water plant.

## 4. Conclusion

While the DSS developed thus far provides a strong basis for decision making, there is some scope for further modification. Key to this is ensuring that the underlying data is accurate and that all parties involved in the decision making process are briefed on the capabilities of the tool. Water grids are not only managed on the basis of cost but also water quality. While water quality is not directly represented in the DSS, future versions can be modified to include volumes and calculate water age and optimize for water age and investigate the differences in operation and cost to that where it is optimized based on price alone.

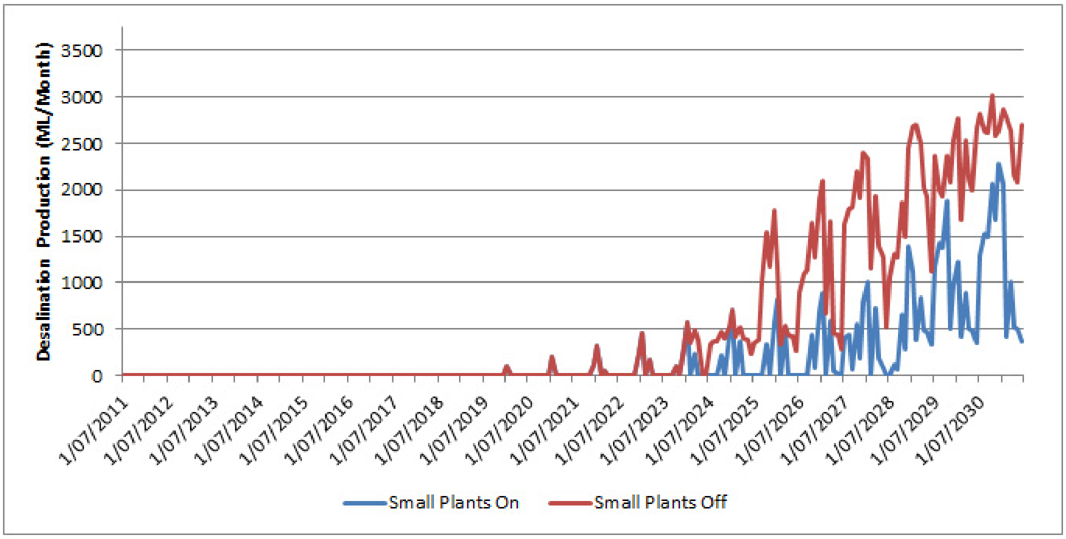


Fig. 4. Desalination plant impact due to removal of smaller WTP.

Given that a previously disaggregated water grid is now a large interconnected water grid, the need for more informed decision making which seeks to capitalize on the efficiency provided through the large grid is particularly apparent. On this basis the DSS described in this paper provides a strong basis for better understanding how this larger grid can be operated and managed now and into the future. This represents a shift in thinking from decisions being made at the local scale to decisions being made at a regional scale.