INTEGRATED WATER SOURCE MANAGEMENT MODELLING: A RISK BASED APPROACH

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ABSTRACT

Watercare is responsible for supplying high quality drinking water to more than 1.2 million people. Over the past ten years Watercare has used an Integrated Source Management Model (ISMM) to assist operational and management decisions. This model, developed by Tonkin & Taylor Ltd, is crucial to the management of Auckland's water sources, and doing so from an integrated risk management, cost minimisation approach.

At the heart of the ISMM is an innovative but now proven optimisation strategy that balances risk-weighted damages from potential supply shortfalls against marginal operational cost. In essence the conflicting objectives of cost-of-operation minimisation and system yield maximisation are resolved based on cost objective functions determined from structured hydrological risk analysis.

The model has become established as an essential tool for Watercare managers, to assist the sustainable management of Auckland's water supply.

During the summer of 2008, when other cities around New Zealand were under water use restrictions, there were no such restrictions in Auckland. Watercare achieved this by effective management of its aquifer, dam and river sources, with the ISMM as a critical tool to inform the Watercare Board on the risk of water shortage and assist management operational decisions.

KEYWORDS

Water supply, optimisation, risk, cost, yield, operations, drought planning

1   INTRODUCTION

Watercare is a Local Authority Trading Enterprise, owned by territorial local authorities of the Auckland region. It is responsible for supplying high quality drinking water to more than 1.2 million people in the greater Auckland metropolitan area. Control of Watercare and its detailed responsibilities are defined in the Local Government Act and various amendments.

Water is taken from the Hunua and Waitakere catchments, the Waikato River, and an underground aquifer source at Onehunga.   It is then treated and distributed to six territorial authority customers, the local network operators who distribute water to households and businesses. The local network operators draw water from the Watercare pipelines at metered supply points and distribute the water to individual properties.

Since August 2000 Watercare has used source management software, the Integrated Source Management Model (ISMM), to assist management and operational decisions. This model, developed by Tonkin & Taylor Ltd, is crucial to the management of Auckland's water sources. It provides the facility to optimise conjunctive source abstractions, and to model various system scenarios to understand and plan for maintenance and future source development.

Since original development of the software in 1999 and 2000, Tonkin & Taylor has worked with Watercare to extend and enhance the model functionality, and extend the hydrological databases that underpin the model.

During the summer of 20008, when other cities around New Zealand were under water use restrictions, there were no such restrictions in Auckland. Watercare achieved this by effective management of its aquifer, dam and river sources. In the winter of 2007, when lake levels were already low, the ISMM software enabled Watercare managers to determine the effect of various future rainfall scenarios to determine a management strategy for possible drought shortfalls.

2   INTEGRATED SOURCE MANAGEMENT MODEL BACKGROUND

2.1   BASIC STRUCTURE

The original ISMM model developed for Watercare had four modes of operation accessible to the user. Each mode is designed to meet specific operational and planning purposes. The original four operational modes are:

- **Real-Time Mode (RTM)** – to provide operational solutions in terms of the optimal withdrawal rate from each source on a daily basis from one to four weeks ahead, by forward simulation of Watercare's headworks operation, based on current storage and catchment conditions, the input demand, operational constraints and forecast rainfall.

- **Operational Planning Mode (OPM)** – to explore medium to longer term implications of various operational regimes, climate change scenarios and resource consent variations. Uses available inflow and demand sequences.

- **Demand Management Mode (DMM)** – to conduct simulation to quantify the potential need to invoke demand conservation programmes. It indicates the reduction in demand required to avoid shortfall for various inflow and demand sequences derived from available inflow and demand sequences.

- **Yield Evaluation Mode (YEM)** – to compute the safe yield of any given configuration of the headworks system, with provision for different assumptions regarding resource consents, operational constraints, and catchment and climate scenarios.

In the first tranche of ISMM enhancements completed in 2002 two further modes were developed and incorporated with the model framework:

- **Forward Risk Analysis Mode (FRA)** – to provide the ability to compute shortfall risk with and without the forecast conditions, thus providing an assessment of the effect of the constraints of those conditions on shortfall risk

- **Demand Reduction Optimisation** (DRO) – to provide a mechanism for determining the optimum Risk Cost Factor (the R-value) for a given demand reduction scheme.

There is a seventh component, which is an internal calculation procedure to compute risk tables, referred to as SYRCALC. This option is used whenever a new water source system configuration is to be modelled. The need arises because each set of risk tables is specific to a particular system configuration, including its associated climate and catchment scenario, and resource consent conditions.

2.2   MODEL HYDROLOGY

The model assesses system yield by simulating operations using rainfall records and rainfall runoff modelling to simulate inflows to the Hunua and Waitakere lakes.

In the development of ISMM three sources of hydrology were developed for use. Two are actual historical sequences. One covered the period from 1911 to 1998. For this period the Albert Park and Waitakere gauges were operating, thus providing two data sources that can validate each other. The second historical record includes the data from 1911 to date and also rainfall data from 1848 to 1910 recorded at Albert Park. The record from 1848 to 1910 cannot be validated against another gauge. However, it does include lower rainfall than recorded after 1920 at the same station, so is a significant data source. As part of recent enhancement of the model, the original databases have been updated to 2007.

A third rainfall sequence used in the model is a synthetically generated sequence that is based on the 1848 to 1998 records. The value of a synthetically generated sequence is that it can be much longer and include sequences that are not in the historical record. Significant research was undertaken to determine methods that generate rainfall sequences that are truly representative sequences of the underlying phenomena based on historical records. A model was developed which produces rainfall sequences that simulate the same response from a battery of tests as the historical record. This model has been used to generate an 850 year synthetic rainfall database, thus providing for risk analysis a 1,000 year record when integrated with the available historic data from 1853.

The rainfall records are converted to dam and aquifer inflows using rainfall runoff sub models that were developed and calibrated as part of the ISMM model development.

2.3   RISK-BASED CONCEPT

Fundamental to ISMM is the concept of a risk of a shortfall in water supply. Providing stored water with notional value that that can be added to the cost of using stored water provides for daily (or weekly) water abstraction decisions that are based on selecting abstractions from the various sources that minimise cost. Here, the cost includes the notional value of stored water.

The bottom line goal of source management is to achieve drought standard performance at least cost.

In practice, control over the use of sources is via short-term (e.g. weekly) abstraction decisions. Consecutive short-term decisions, actual rainfall and demand, determine the path the system will take. These weekly decisions must be guided so that the drought standard performance is achieved at minimum cost.

This approach was developed from observation that, for the Watercare headworks system involving significant storage, abstractions are determined at weekly intervals and in this process a decision has to be made whether to use more expensive pumped water or cheaper stored water. More expensive water is used when it is assessed there is a chance of a shortfall given current storage levels, expected demand and time of year (i.e. seasonal likelihood of rain). If there is no significant chance of shortfall, stored water will be used if cheaper. This is reality at weekly decision-making level. Therefore, if the probability of shortfall is known a more informed decision can be made.

In the ISMM the probability of shortfall is given a weight to convert it to a cost that is added to stored water operating costs, and the cheapest overall sources chosen to meet demand. The weight given to shortfall probability is increased in favour of more expensive non-storage sources until the system is demonstrated to meet the required drought performance standard. At this point the system will meet the standard at least cost.

This risk approach, in essence, gives stored water a value that is based on the probability of shortfall. This is called the value of stored water. The weight factor is referred to as the R value.

The probability of shortfall is computed by many simulations - starting with overall system storage, at a given month, and applying a standard demand profile. Each simulation runs until either a shortfall occurs or storage recovers to a level considered to indicate "end of a drought", typically 100 % full. If the lakes fill at some time in the future, before a shortfall is encountered, conserving water now will have no system drought performance benefit. The percentage of simulations that have a shortfall provides an estimate of the probability of shortfall given the start storage, time of year and demand.

2.4   OPTIMISATION

Achieving drought standard performance at minimum cost involves selecting the optimum combination of the shortfall risk weight factor, R value, allowing also for the spill risk of nearly full lakes (when water available for supply might otherwise be lost).

Water stored in dams that are nearly full is not as valuable as water in dams that are not so full. Thus in the model the stored value of water is diminished by the probability of spill. The effect is to reduce spills between total storage going from full to a shortfall by making full, expensive dams sitting at 100 % reduce in volume to say 90 % as shortfall risk increases. The extra cost is that expensive abstraction is involved reducing the volume and keeping it reduced by abstracting the inflow.

For the dams involved in the Watercare system, the inflows when on the way to a shortfall are low. The total water involved in such spills that could be eliminated on the way to a shortfall has a minor influence on yield.

The scaling of shortfall risks adds significantly more water to the yield by using earlier expensive sources such as the Onehunga aquifer and Waikato River.

3   ENHANCED FUNCTIONALITY

Since the commissioning of the original model in 2000, Tonkin & Taylor has worked with Watercare to extend the model capability and functionality. These enhancements have generally been in response to the experience of Watercare operators and to provide flexibility in modelling operational aspects of the system, and in reporting to assist management decisions.

Enhancements have provided Watercare modellers with greater discretion to adjust lake and treatment station capacities as they may vary for instance during maintenance or capital works upgrading activity. Lake and hydrological databases have been updated with new information that has become available for surveys and longer gauging records. This has included cost and revenue databases associated with pumping, treatment and hydro-electric generation.

The Rainfall Runoff models that underpin the model have recently been re-calibrated using with 2000-2007 data, and based on back calculation of lake inflows in this period.

The original software included for the hydro-electric generation capacity installed at Mangatangi and Waitakere dams. The model has been updated to include the machine characteristics for the generators since installed at Cosseys, Wairoa and Upper Mangatawhiri dams. These are included as part of the overall system for optimisation of the system operation to supply demand based on cost.

The model now includes also for possible future domestic storage for non-potable supply into the model as an additional source.

Clearly the model was developed with the programming technology available in 2000. It became apparent that limitations were imposed by this technology given ongoing development of programming languages and software interfaces, and more importantly that much of the original model technology would not be supported in the future. To ensure the model can be run and supported by the software development tools available for

the next 10 years, the 'at risk' older technology used in the original model code was recently replaced by up to date technology equivalents.

4   ISMM MODEL IN WATERCARE

In the nine years of operation in Watercare, the ISMM has been used in planning support to managers to assist decision making for routine weekly operations, planning of system maintenance and capital works, and resource consent applications. Various specific tasks have included:

- Modelling of water balance and optimal allocation of sources to meet demand for weekly operations planning

- Determination of least cost basis for operating system (Waikato) that achieves system performance.

- Analysis of impact of various compensation release scenarios to assist planning and support resource consent applications, including effect on yield and operating cost.

- Annual budgets computation based on coming year's expected demand and a range of rainfall patterns. Budget costs are computed for each component of operating costs, treatment, pumping and hydro-electric generation revenue.

- Impact analysis for scenarios involving loss of significant components for a period of time either as part of planned system component maintenance and/or upgrading, or as part of risk analysis to determine consequences of damage caused by events such as earthquakes. Impact assessment includes risk of shortfall, how long system could continue to meet demand, and cost impacts.

- Analysis of demand and system component changes at various times in the future to assist planning of system expansion and timing of capital works.

- Conjunctive analysis of the impact of roof rainfall capture given a range of tank sizes, roof areas, house occupancy rates, and per capita consumption. Analysis includes conjunctive impact on yield and costs, but also provides an understanding of how system components such as storage will behave during droughts.

- Development of a demand management profile based on storage and time of year to achieve system performance goals with least impact on consumer and costs.

- Investigation of the impact of various scenarios of rainfall pattern changes caused by climate change, with identification of effect on system yield and operating costs.

- During droughts used to assess system behaviour for a range of possible demand and rainfall cases to aid decision making. An example is assuming that the overall system storage capacity is at a stage similar to previous drought events.

5   CASE STUDY: 2007/08 DROUGHT

In June 2007, after a relatively dry autumn period, the storage of the Watercare lake system was at 59 % capacity. At this time there were concerns about continued low rainfall and what the implications might be for the security of supply over the next twelve months. To clarify this risk Tonkin & Taylor undertook modelling of the system operation for the expected demand under various future rainfall scenarios.

At this time Watercare also received advice from NIWA regarding the likely climate conditions through the Spring of 2007 and Summer of 2008. NIWA indicated three scenarios:

- Most likely (55 % chance): Spring rainfall 110 % to 120 % normal

- Normal rainfall (40 % chance)

- Unlikely (5 % chance):   Spring/Summer rainfall 80 % normal

To determine the storage response in the lakes over the 2008 summer period two sets of scenarios were modelled:

- From the historical rainfall records five years were identified in which the rainfall across the catchment (Hunuas, Onehunga and Waitakere) were near the median and mean values for the catchments. These were selected as normal years.

- Additionally rainfall data from the each of the fourteen month sequences (July to August) in the 150 year historical record was used as input to determine where storage response if historical conditions were repeated.

The ISMM model was used to simulate the Watercare operations through to August 2008 to identify the likely storage conditions and risk of shortfall. The modelling was carried out for various operational approaches including cost-optimised (business-as-usual) operation, and also considering priority use of the Waikato source and invoking demand management measures.

The results of the modelling showed that for the three NIWA climate scenarios the minimum storage level in the lakes would be:

- Most likely rainfall: 56 %

- Normal rainfall: 54 %

- Unlikely rainfall: 46 %

Utilising the Waikato at greater capacity than optimally required raised the minimum storage level in the Unlikely Rainfall Scenario from 46 % to 59 %. Actioning Demand Management raised the minimum storage to 64 %. The projected August 2008 storage level in the system was over 70 % for all cases.

Modelling showed that for optimal management of the system during historical rainfall sequences there would not have been any year when storage in the lakes was exhausted. Figure 1 shows a trace of total storage level in the lakes for the 150 years on record. Each year was modelled starting from total system storage of 59 %, equal to the storage level at the beginning of July 2007.

For the historical record the lowest system storage reached modelling optimal system operation was 10 %, corresponding to 1860 and 1878. In the more recent dry years of 1983 and 1994, system storage would have dropped to 20 % and 26 % respectively. These modelling results provided critically useful information, given that they are based on recorded rainfall, i.e. real-life rainfall seasonal rainfall scenarios. In particular the modelling of the 1993/1994 data gave a indication of the system performance during a period of water restrictions experienced and still remembered by many of the Watercare management team.

Figure 1:   *Modelled Watercare storage levels for 2007/2008 based on historical rainfall*
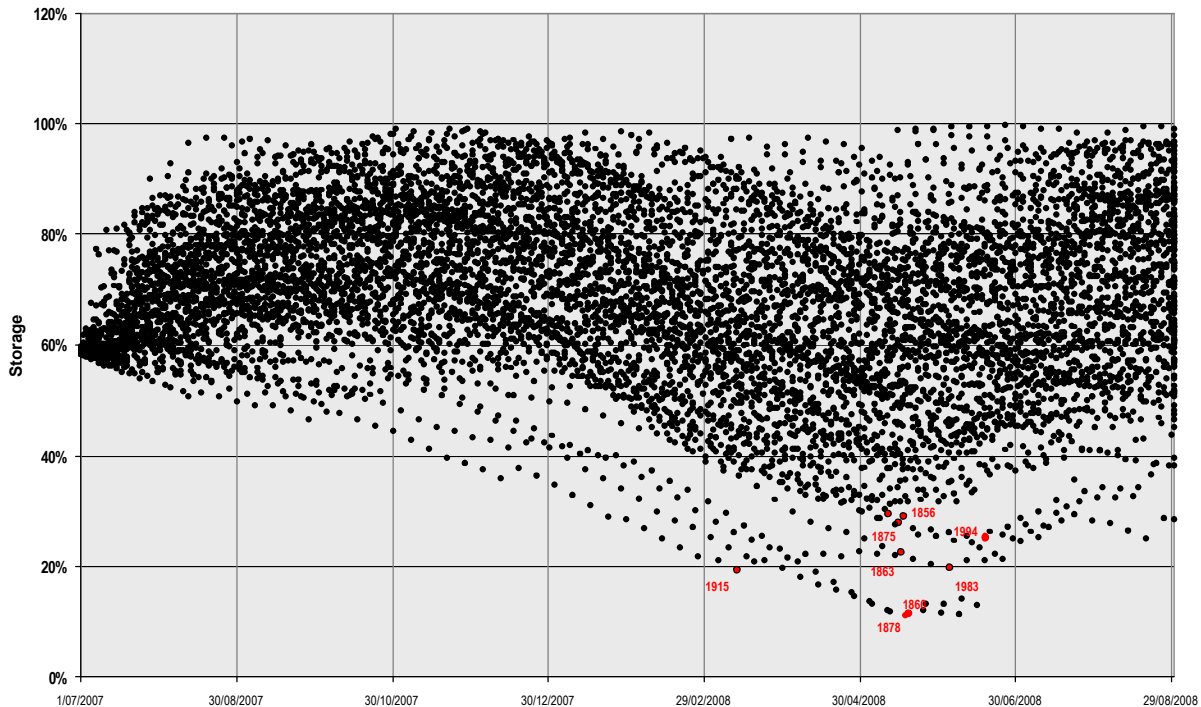
The ISMM modeling based on the NIWA climate scenarios was presented to the Watercare Board in June 2007. The outputs demonstrated that for the most extreme case (i.e. the most severe droughts in the 150 year historic record, with no demand restrictions in place and Waikato operating to minimize costs) minimum lake storage would remain above 10% and that the Watercare drought standard would be met. Based on the worst climate forecast, lakes levels were forecast to remain over 50% full and a recovery was expected.

ISMM provided reassurance to the Watercare Board that no additional contingency measures or water demand restrictions where needed at that time. In the following month (July 2007) above average rainfall was experienced in the Hunua and Waitakere ranges and lake levels recovered to 70% as predicted.

6   CONCLUSIONS

For nearly ten years Watercare has been using an integrated source management model (ISMM) in operations and planning for optimisation of water supply from its lakes, Waikato River and Onehunga aquifer sources. The model provides a means to determine optimal conjunctive draw-off from the various sources based on cost to meet a desired security of supply standard. Since its original development, the model capability has been enhanced to provide greater functionality based on Watercare experience of its use and new applications identified.

The model has enabled detailed investigation of various operational scenarios using historical and synthetic rainfall records, and to determine the impacts of management decision and to assist planning of capital works.

In 2007, when total lake storage was lower than usual for the time of year, the model was used together with seasonal rainfall scenarios from NIWA to model the possible system response and the likelihood of water shortfall if drought conditions became established. The Watercare Board were able to be informed on the risks of a water shortage and Watercare managers were better informed to make decisions about operations of the lakes and the Waikato source to minimise the risk of any water shortage.

In the past decade the model has become fundamental to the effective operation, optimisation and management of Watercare's water resources, and a critical tool in the supply of safe drinking water to the people of Auckland.

ACKNOWLEDGEMENTS

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