The value of water in storage: implications for operational policies

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ABSTRACT

With desalination plants becoming an increasingly common feature of water supply systems for major cities, the options for managing water security are now markedly different to past times when the short-term response to low water availability essentially revolved around reducing usage. The operation of desalination plants and other components of diversified water supply systems now enable operators to increase availability, essentially by producing water. The operation of such systems clearly impacts operational costs but, more subtly, also impacts future augmentation decisions. This can have major cost implications as there is a trade-off between the costs of operating a water supply system and the probability and timing of future augmentations that leads to important differences in the economics of reliably supplying water.

This paper first summarises an economic analysis framework in which to explore the interaction of short (operational) and long (capital investment) term decisions towards maintaining water security. It then explores the implications of different operation approaches in Melbourne's water supply system, assuming a planned augmentation pathway under conditions of low water availability. We assume augmentation decisions are prompted by critically low water availability events, rather than long-term reliability analysis. We show that the majority of the variation in cost of maintaining a reliable water supply is associated with impacts of operational rules on likely capital investment and that this results in a strong interaction between short and long-term decision making.

The outcome of this work has implications for both operational decision making and augmentation planning for urban water supply systems. These implications are relevant to any water supply system where a climate independent water supply source, such as desalination, can be accessed.

INTRODUCTION

Maintaining a sufficiently reliable water supply in the face of hydrologic variability is a long standing challenge. For many major cities this has involved developing reservoirs to store water and distribution systems to transport that water. In the past water supplies were expanded as needed, with such expansions often, but not always, prompted by a water shortage during droughts. In recent times, the ability to produce water through processes such as reverse osmosis desalination has reached a point where it is economically feasible at large scale, as evidenced by installation of desalination plants servicing most of Australia's major cities. An important change is the existence of climate independent water sources and our ability to deliver those relatively quickly and with a higher level of surety than developing major new reservoirs that are dependent on streamflows. As a consequence, both the operation and approach to augmentation of our water supplies can be changed, with benefits in terms of both risk management and cost. This paper presents a study that investigates the interactions between operation and augmentation of Melbourne's water supply system, with a view to estimating the value of water in storage and examining operational and augmentation policies from hydrologic risk and economics perspectives.

Historically short-term water shortages have typically been managed by reducing demands, through restrictions and/or education. Risk was typically evaluated and managed based on assumptions about stationary statistical properties of historic inflows (McMahon and Adeloye, 2005). The lack of climate independent water supplies and long lead-times on reservoir expansions meant that supply side actions were typically not available in the short term. In principle, water supplies were constructed to meet demand with a certain reliability based on an understanding of variability in reservoir inflows and likely growth in demand. This is in essence a long-term view, although short-term shortages typically generated demands for supply improvements. Added to these issues is the impact of climate change which is likely to impact both climate forcing and runoff response of catchments (Kiem and Verdon-Kidd, 2010). More recently it has been recognised that the internal response of catchments can also result in shifts in the rainfall-runoff relationship under sustained changes in climate forcing that further amplify the effects of reduced rainfall (Saft et al., 2016; Saft et al., 2015).

In 1997 a 13 year dry spell began in Eastern Australia, referred to as the Millennium Drought (van Dijk et al., 2013). This strongly challenged the view that future planning could be predicated on historical observations (aka statistical stationarity), an assumption which is now recognised as inapplicable, at least in the longer term. In 2006, Melbourne's water supply experienced record low inflows and by the end of the year storages were below 40%. In May 2007 they were below 30% (www.melbournewater.com.au, accessed 13/7/18). In two separate years of the Millennium Drought (1997 and 2006), the water harvested by the supply system was only about one quarter of the unrestricted demand, or just over 100GL in each year (Udaya Kularathna, pers. Comm.). In the face of the ongoing drought, and dramatically declining storage levels, on June 19, 2007, the Victorian Premier Steve Bracks announced a 150GL/a desalination plant would be built for Melbourne. Construction of the North-South was announced at the same time (The Age, 19 June 2007).

As with all infrastructure, there is a trade-off between risk and expenditure. There are also more and less efficient ways of obtaining a given risk outcome. With a desalination plant in existence, a key question is how much operating expense to incur, through running the desalination plant or imposing restrictions which have social losses, versus the risk of storages falling to a point that prompt an early augmentation of the water supply system. The "OPEX" of a water supply versus its future "CAPEX". Given that future water inflows are uncertain and that any action to increase water supply takes time, it is always necessary to maintain some water reserves in a surface water-based supply and remedial action is needed if water levels fall too low, often involving supply augmentation when storages become sufficiently low. Because operating a desalination plant changes water storage, an interdependence between operation and augmentation exists that needs to be accounted for. To inform operation and investment decisions, the economic implications of decisions, including the interactions between short and long-term, need to be quantified, which is the aim of this paper. A more complete report is available Western et al. (2018).

ANALYSIS FRAMEWORK

We develop a reliability cost curve for the Melbourne water supply system that enables us to value the water in storage, as a function of that storage. The reliability cost curve shows the expected costs of ensuring a given level of reliability as a function of initial storage, given a certain set of operating and augmentation rules. In general we make the following assumptions:

1. There is a tolerable level of risk of not being able to meet demand. In this particular case, this is characterised as a minimum reserve storage level in the system that is likely to occur under historically low inflows. Not meeting demand implies not meeting stage 4 restricted demand in

this case, or, more generally, not meeting the minimum level of service. It should be noted that the probabilities associated with this criteria are poorly defined for a variety of reasons, most notably climate non-stationarity.

2. We assume that there is a series of climate independent water supply augmentations that can be made that have known capacity, known lead-time from investment decision to commissioning and a known decision criteria, which is related to 1.
3. We assume that there are a series of costs associated with maintaining 1 and implementing 2 where necessary. These costs relate to: aspects of operating the system that relate to maintaining the volumetric availability of water, for example running the desalination plant; investing in system expansions where required; and social losses associated with not meeting unrestricted demand at the prevailing water price. We do not attempt to quantify demand as a function of price, which would be a more rigorous means of quantifying social loss (benefit). Costs are discounted to the start of the simulation period and provide a basis for comparing scenarios. Routine system operating and maintenance costs are not included.
4. We assume that the system is operated under known starting conditions (which is the reality) and with uncertain future inflows and demands. In this case this, future uncertainty is represented by stochastic inflow and weather sequences and an underlying demand growth. The uncertain future is represented by two scenarios with conditions like the last 20 or 40 years respectively.
5. We undertake system simulations with a modelling framework described below from a range of initial starting storages (20%, 25%, 30%, … 100%), for a period of 20 years, which is more than sufficient to reach long-term hydrologic behaviour under the assumptions made and is well beyond the delivery time of supply augmentations. The reliability cost is the expected net present cost obtained by averaging across 10,000 realisations.

This analysis results in a series of outputs that can inform operational and investment decisions. Central to these are a series of costs including desalination operation (and associated pumping), north-south pipeline operation and opportunity cost, social losses due to restrictions, social losses associated with being unable to meet stage 4 restricted demand and capital investment costs associated with expanded and/or new desalination plants. A range of other system performance outcomes are also simulated such as storage levels, timing and likelihood of augmentation decisions, and occurrence of restrictions and shortfalls below stage 4 restricted demand.

APPLICATION TO MELBOURNE'S WATER SUPPLY

System model

A model of the Melbourne Water Supply System was developed for this project and written using a vectorised coding approach designed to efficiently facilitate stochastic simulations. This was done to allow a large number of stochastic simulations to be run efficiently and, more importantly, to enable a range of augmentation decision making and operation of the resulting augmentations to be simulated within the model. This could not be easily achieved with the current REALM model of the system. The conceptual model created of the Melbourne water supply system simulates the system head works, plus Cardinia Reservoir, with demand allocated to three zones: Cardinia, Sugarloaf, and "the rest" (Figure 1). The model operates on a monthly time step. The model includes:

- Stream inflows;
- The head works storages;
- Releases to downstream for environmental and passing flow purposes;
- Evaporative losses from Cardinia, Sugarloaf, Tarago and Yan Yean reservoirs;
- Capacity constraints at various points around the system, particularly in bulk water transfers and pumping;

- Operation of the Victorian Desalination Plant (VDP) and the North-South pipeline;
- Possible augmentation of the VDP and construction and augmentation of a second desalination plant; and
- Melbourne metropolitan and regional water authority demands.

Silvan Reservoir is treated as a node in the system that is held at a constant storage level and subject to evaporative loss. Greenvale Reservoir (not shown) is also assumed to have constant storage and an evaporative loss.

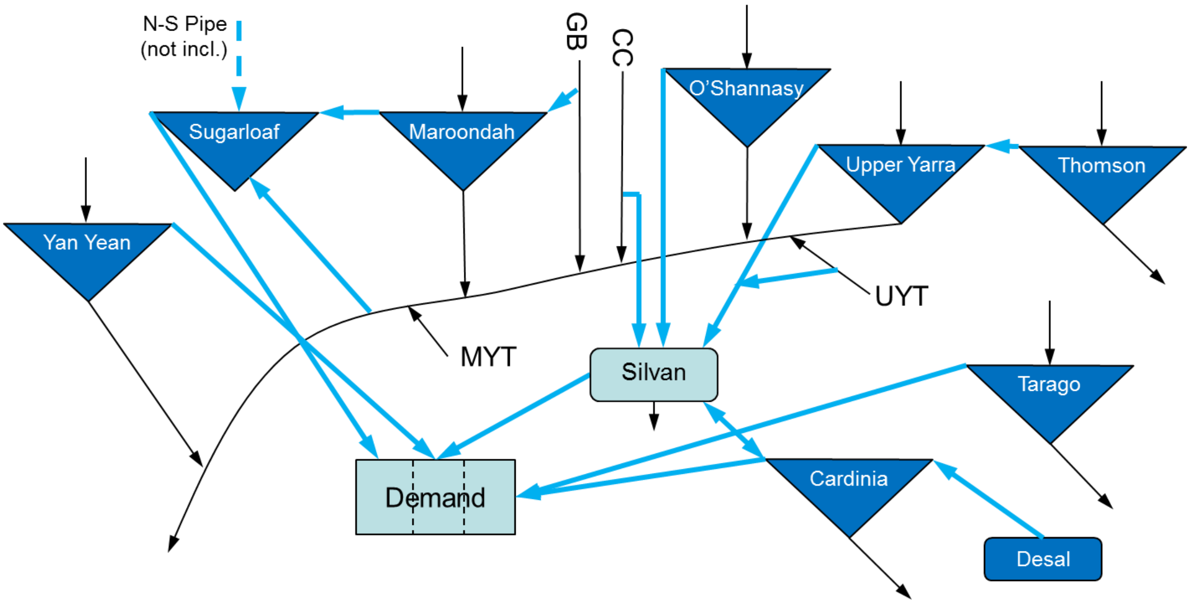

Figure 1: Melbourne's water supply system as represented in the conceptual simulation model.

The key computational steps in the model are as follows.

1. Determine storage in all reservoirs under specified operating rules.
2. At the start of December, the model checks whether restrictions should be applied based on the active storage available and determines what the restriction level and associated savings are.
3. At the start of January, the model checks whether a desalination order needs to be placed and what volume that order is. The desalination is distributed equally over the following 12 months (i.e. January to December). The desalination plant operating arrangements are discussed further below. The need for North-south pipeline transfers in accordance with operating rules are also determined at this point and distributed equally across the year.
4. Augmentation decisions are made at the start of January based on storage levels and augmentation delivery lead times.
5. Demands are then determined based on the hydrological realisations, using standard Melbourne Water demand modelling, and on the restrictions level.

The water supply system model was tested against eight 50 year simulations made using Melbourne Water's REALM model. These simulations used four inflow scenarios that included the historic inflows from 1967 to 2016 and three modified versions of these inflows that were statistically adjusted to match post 1975, post 1997 and "return to dry" (1997-2009) conditions. Each of these were simulated with and without the Victorian Desalination Plant operating. The comparisons showed close agreement between REALM and comparison statistics are shown in Table 1.

Table 1: Comparison of system simulations and REALM simulations.

		Demand Supplied			Average Annual Storage		
Scenario	Desal	Bias	R^2	CoE	Bias	R^2	CoE
Historic	No	1%	0.85	0.85	6%	0.99	0.97
Historic	Yes	0%	0.94	0.94	4%	0.99	0.95
Post 1975	No	1%	0.87	0.86	6%	0.99	0.96
Post 1975	Yes	0%	0.92	0.92	3%	0.99	0.95
Post 1997	No	-1%	0.81	0.81	-5%	0.99	0.98
Post 1997	Yes	0%	0.78	0.78	4%	0.86	0.78
Return to Dry	No	-3%	0.89	0.86	-15%	0.99	0.94
Return to Dry	Yes	3%	0.58	0.46	9%	0.70	0.52

Augmentations were modelled by checking water storage annually to determine if an augmentation should be constructed. In this case the augmentations consisted of a series of projects commencing with a 50GL/a capacity augmentation of the Victorian Desalination Plant at Wonthaggi, construction of a second desalination plant (50GL/a) and finally augmentation of that plant (50GL/a). Augmentation decisions were based on a storage threshold that was determined on the basis that storage levels should not fall below 40% under maximum desalination production and a scenario of low harvesting informed by millennium drought conditions over the assumed lead time for augmentation delivery. Further detail is given below.

Inflows to the various harvesting points in the system were simulated with the Wathnet 5 software. The stochastic model is a multi-site, multi-season, multi-state contemporaneous autoregressive model. The model represents relationships between sites, variations across the year and includes first order autoregression. The inflow scenarios used to train the stochastic model were supplied by Melbourne Water and are similar to standard planning scenarios used by Melbourne Water, with some update of the data for recent conditions. The simulations were based on 10,000 replicates, each 20 years long. It should be noted that these scenarios include the possibility of more severe droughts, but only to the extend they are statistically consistent with the inflow scenarios used to fit the stochastic models (i.e. we make an assumption of stationarity) and they include climate change to the extent that the last 20 years (including the Millenium drought) might be representative of near term climate change. We feel that this is reasonable given our focus on implications of system operation on augmentation. Of course, a wider range of climate scenarios could be used, noting the need to also deal with changing catchment response. It is also important to note that the future could produce more extreme conditions.

The system performance is examined under two different sets of hydrological realisations. These expectations are stochastically generated synthetic streamflows based on the historic inflow patterns. One set is based on historic inflow adjusted to represent the past forty years of inflows while the second is representative of the past twenty years. The two sets of hydrological realisations are referred to as Post 1975 and Post 1997 respectively. Essentially the assumptions behind these two scenarios are that inflows are statistically like the last 40 years (Post 1975) or like the last 20 years (Post 1997).

Some high level statistics for the streamflow sequences are shown in Demand was simulated using the standard Melbourne Water approach (Smith and Baker, 2013) and a medium demand grow scenario for 2017-2036. Demand estimation requires monthly weather variables (rainfall, raindays and temperature) and these were generated stochastically along with system inflows as described above.

Table 2. Note that the values in this table are for the total inflows in streams accessed by Melbourne Water harvesting sites, with the exception of the Thompson River where the Melbourne Water share (94 per cent of total streamflow) is used. Many of these harvesting sites rely on pumping or diversion to an aqueduct or pipeline and it is not physically possible to harvest the higher flows at those points.

Demand was simulated using the standard Melbourne Water approach (Smith and Baker, 2013) and a medium demand grow scenario for 2017-2036. Demand estimation requires monthly weather variables (rainfall, raindays and temperature) and these were generated stochastically along with system inflows as described above.

Table 2: Statistical characteristics of synthetic streamflows

	Post 1975 (GL)	Post 1997 GL
Inflow Wettest Sequence (GL/a)	1,219	926
Mean Inflow (GL/a)	875	700
Standard Deviation (GL/a)	286	209
10 Percentile Inflow Sequence (GL/a)	773	629
Inflow Driest Sequence (GL/a)	570	489
Driest 10 year Inflow Sequence (GL/a)	477	400
Driest year (GL/a)	155	160

A variety of decisions in the model depend on storage thresholds, such as desalination orders, restriction implementation and north-south transfers. As demand grows (and system configurations change) different thresholds are appropriate. Therefore, for simulations quantifying the reliability cost curve, trigger thresholds for desalination orders, restrictions, etc were varied to reflect changes in demand. This was done as follows. The thresholds in Table 6 were first converted to a storage time related to the portion of demand dependent on climate variable sources, τ, using:

$$\tau = \frac{\beta * S_{cap}}{\bar{D} - Q_{desalCap}} \qquad 1$$

where $\bar{D}$ is the (climate independent) annual demand for the first year, β is the threshold value at the start of the simulation, S_{cap} is the system storage capacity, and $Q_{desalCap}$ is the installed desalination capacity. As demand and installed capacity changed throughout the simulation, the triggers were recalculated by rearranging the above equation and using values for the relevant year. These calculations always assume an average year i.e. no adjustment of demand due to weather. This approach enables adjustments to the operating arrangements as the system and demand changes and maintains a constant threshold in terms of an equivalent time reserve.

Cost estimations

Cost estimates were made for system components associated with maintaining the system bulk water availability or reliability including:

- Desalination operation, including associated pumping;
- Social cost of restrictions and shortfall below stage 4 restricted demand;
- North-South pipeline interbasin transfer operation and opportunity cost; and
- Capital cost of augmentations.

All costs were discounted to current time based on Melbourne Water's post tax real interest rate of 4.2 percent. These net present costs formed the basis for comparison between operation scenarios. Table 3 provides key operating costs for the Victorian Desalination Plant. Here, S_t is the system storage as a proportion of total storage capacity.

Table 3: Victorian Desalination Plant operating arrangements and costs

Order level	S_t (at 1 January)	Order (ML) (Pre-augmentation)	Order (ML) (Post augmentation)	Operating cost ($/ML)
0	$S_t \geq 0.65$	0	0	$0
1	$S_t < 0.65$	50,000	66,700	$560
2	$S_t < 0.625$	100,000	133,300	$590
3	$S_t < 0.6$	150,000	200,000	$610

To estimate the social costs associated with restrictions in line with the proposal in Water for Victoria, DELWP instigated a cost of restrictions project. Marsden Jacob Associates (2017) undertook analysis that applied estimates of the social costs associated with restrictions to the Victorian restrictions regime and prepared costs that could be used in water resource models. Household costs incurred due to restrictions are based on McNair and Ward (2012). Business Costs are based on Hensher et al. (2006). Public Open Space costs are based on Weller and English (2008). Water Corporation Costs are based on Marsden Jacob Associates (2017) analysis of publicly available financial data. Table 4 summarises the operation of restrictions and associated social costs assumed here. These costs include costs to the community and costs to authorities of implementing restrictions.

Table 4: Trigger levels, estimated water savings and social costs of restrictions

Stage of restriction	Trigger storage (at 1 December)	Estimated range of savings (of total demand)	Assumed savings	Social costs per Ml
1	$S_t < 0.60$	2-3%	2.5%	$3,310
2	$S_t < 0.50$	5-7%	6%	$3,090
3	$S_t < 0.40$	8-12%	10%	$2,700
4	$S_t < 0.30$	14-16%	15%	$7,390

Where stage 4 restricted demand could not be met, a social cost of $30,000/ML was assumed based on Grafton et al. (2014) when estimating a scarcity price for Sydney's water supply system. Grafton et al's estimate of social costs of water shortages were made based on the experience of the Barcelona utilities who imported bulk water by sea in 2008 when confronted with low reservoirs.

The cost of transfers from the Goulburn River Basin via the North-South pipeline to Sugarloaf Reservoir were estimated as the cost of pumping and treatment ($199/ML) plus a variable opportunity cost associated with foregoing irrigation usage. The opportunity cost was estimated based on temporary trade market prices modelled using a regression relationship with Goulburn system storage in December. To maintain the correlations between water availability in the Melbourne and Goulburn systems, the Goulburn system storage was simulated using a statistical model driven by the four main inflows to the Melbourne system (Maroondah, O'Shannassy, Upper Yarra and Thomson reservoirs) combined with a stochastic component incorporating a 1 year autocorrelation (Western et al., 2018).

In undertaking this analysis it was assumed that augmentations precipitated by low storage levels would be in the form of expanded desalination capacity. The expansions were a 50GL/a addition to the Victorian Desalination Plant at Wonthaggi, construction of a second 50GL/a desalination plant and finally augmentation of that plant to 100GL/a capacity. The associated capital costs were assumed to be $720M, $1950M and $720M respectively. For the base scenarios lead times were assumed to be 3.5 years, 5 years and 3 years, respectively, and a scenario with a short lead time (2 years) for the first expansion was also considered. In calculating the trigger storage for each augmentation, it was assumed that storages should not fall below 40%, assuming maximum use of available desalination capacity and minimum harvestable inflows. The choice of minimum harvestable inflow was guided by harvested volumes for different durations during the millennium drought and these were dependent on lead time with harvesting rates of 180, 200 and 210GL/a for durations of 2, 3/3.5 and 5 years, respectively. Once an augmentation was triggered, subsequent augmentations were not allowed until that augmentation had been commissioned.

Scenarios

Five scenarios were considered to explore a range of potential variations on operating approaches in terms of desalination ordering, the operation of the north-south transfer and the lead time for the first desalination augmentation. A base case was constructed that approximates current practice. The base case had desalination operation as specified in Table 3, a lead time, t_{lead}, of 3.5 years for the first augmentation and north-south transfers of 70GL/a when system storage, S_t, fell below 30% at 1 December. Table 5 describes the operation rule changes for each of the four alternate scenarios.

Table 5: The four alternative scenarios operating rule changes

	Operational change	Base case	New operating rule
Scenario 1 Use Desalination Less	Desalination ordering New trigger levels	$S_t < 0.65$ $S_t < 0.625$ $S_t < 0.60$	$S_t < 0.55$ $S_t < 0.525$ $S_t < 0.50$
Scenario 2 Use Desalination More	Desalination ordering New trigger levels	$S_t < 0.65$ $S_t < 0.625$ $S_t < 0.60$	$S_t < 0.75$ $S_t < 0.625$ $S_t < 0.60$
Scenario 3 Use NS Pipeline More	North-South Pipeline New trigger levels	$S_t < 0.30$	$S_t < 0.70$
Scenario 4 Reduced augmentation time	Augmentation trigger Reduced augmentation timing	t_{lead} = 3.5y	t_{lead} = 2y

RESULTS

Base case

In this section we present an overview of the base case to illustrate the development of the reliability cost curve, the simulation behaviour and the various cost components. For each initial storage value, 10,000 inflow and demand replicates were run, resulting in timeseries of storage, supplied water, restriction behaviour, desalination production, north-south transfers and augmentation decisions, among other outputs. Figure 2 shows the storage averaged over all realisations for each month of simulation and for each initial storage. The distinction between S_0 values of 20% and 40% and the other values reflects a difference in how often the system is augmented and the dependence of operating rules on desalination capacity (see equation 1). In essence, the system is always augmented at the start of the simulation for S_0 values of 20% and 40%, whereas for high values of S_0, the system is augmented about half the time for the post 1997 inflow scenario.

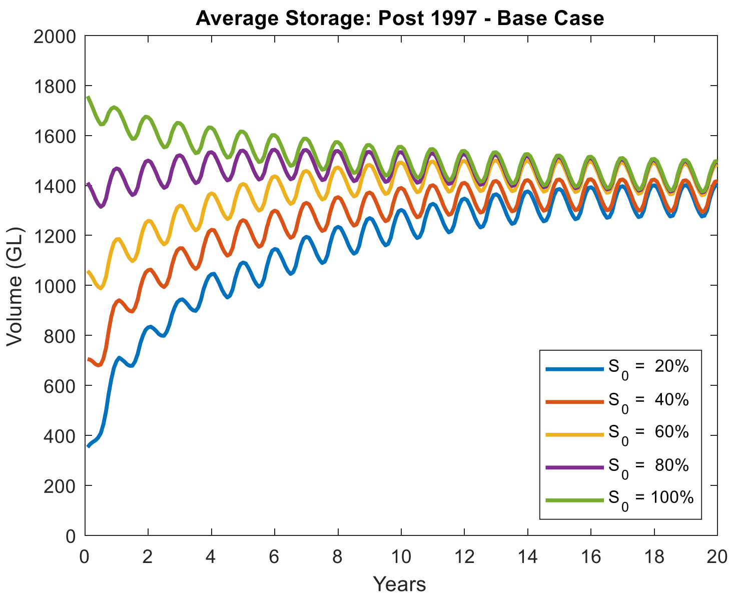

Figure 2: Storage behaviour, Post 1997 Base case, Initial storages ranging from 20 to 100%.

Figure 3 illustrates the contributions of different costs to maintaining water supply reliability averaged across realisations, as a function of initial storage, for the base case and Post 1997 inflow scenario. It can be seen that the three significant cost components are capital expenditure on augmentation, operation of the desalination plant and social costs of restrictions. Operation and opportunity costs of North-South transfers, of pumping from Cardinia to Silvan Reservoir during high usage of desalination and social costs of not being able to meet stage 4 restricted demand are small on average. This is in generally due to the costs being incurred rarely, that is for a few realisations, typically for very low initial storages. The total cost curve shows the overall cost of maintaining volumetric supply reliability as a function of initial storage. Note that the significant increase in capital costs as S_0 declines from 55 to 50% relates to the augmentation threshold at the start of the simulation period being between these two values, so the expansion of the Victorian Desalination Plant is always triggered for $S_0 \leq 50\%$. The slight increase in capital cost as S_0 decreases below 50% is due to occasional second and sometimes third augmentations occurring in low inflow realisations.

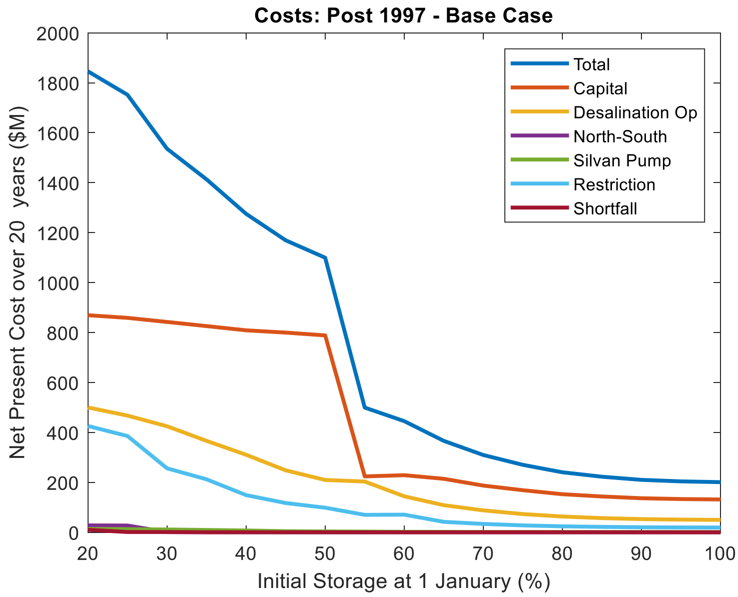

Figure 3: Components of the RCC, Post 75 and Post 97 Base case.

Comparison of Scenarios

Four alternative scenarios are also considered (Table 5, Figure 4). Each of these represents a change in only one element of the operation or augmentation aspects of the simulations. The More Desalination case reflects more frequent small (50GL/a) orders due to a 10% higher storage threshold for the small orders. Less Desalination reflects less frequent placement of all desalination orders due to a 10% reduction in storage thresholds for all levels of desalination orders. The North-South Pipe Line scenario reflects a change in the storage at which transfers occur from 30% to 70%. The Low Augmentation Lead Time reflects a situation where detailed planning of the first augmentation of the Victorian Desalination Plant is in place enabling commissioning of expanded capacity within two years of the decision to expand the plant, as opposed to 3.5 years.

Figure 4 shows that there is a substantial difference between inflow scenarios, particularly where initial storages are in the desirable operation range (above 60%), with the Post 1997 scenario (i.e. flows like the last 20 years) showing higher costs due to lower inflows. There are also substantially greater differences between scenarios in the Post 1997 scenario than in the Post 1975 scenario. This is due to the system being more stressed in the Post 1997 scenario due to lower inflows and hence operation becoming more influential.

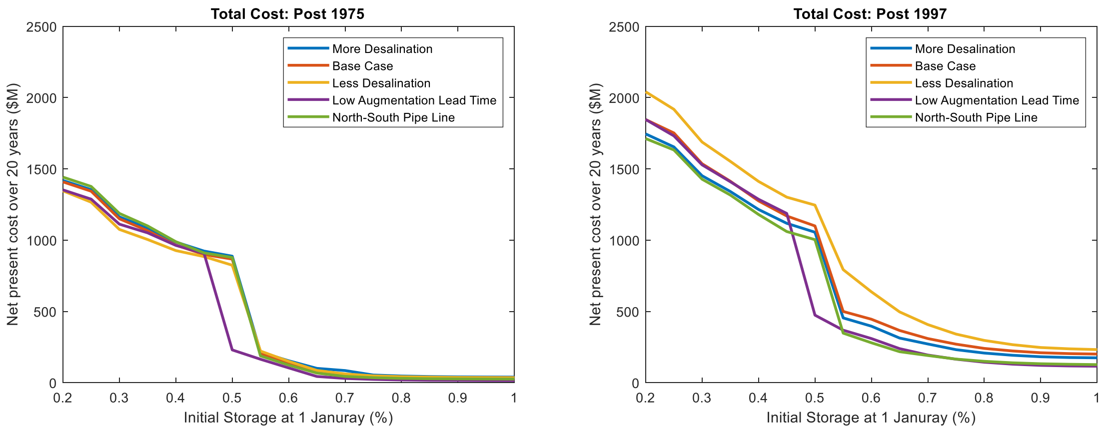

Figure 4: Reliability Cost Curve, Post 1975 and Post 1997, alternative scenarios.

The most important difference in costs between the different scenarios is variation in the augmentation capital costs. Figure 5 shows the frequency of occurrence of the first and second augmentations for the different scenarios, as a function of initial storage. Capital costs are essentially proportional to this frequency of occurrence. The reason that the total costs of alternative scenarios differ relates to how frequently the costs of various actions associated with maintaining a reliable water supply are incurred. At 60% initial storage (roughly recent conditions), the More Desalination case leads to operating the desalination plant more frequently, at a higher storage. This results in a greater buffer for drought conditions is created in the water supply system in the Post 97 realisations. As a consequence, the percentage of realisations requiring an augmentation is approximately halved at initial storages above 55 per cent when operating the desalination plant more frequently, compared with less frequently. Utilising the North-South transfer is also effective at deferring desalination plant expansions, as is reducing the lead time. The reduction in lead time is effective because the lower augmentation threshold allows more time over which high inflow events can contribute to a system recovery.

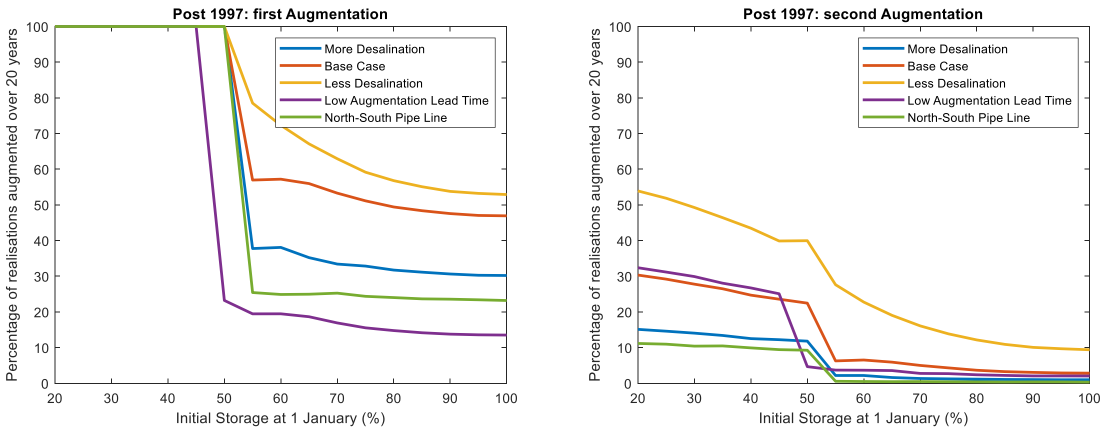

Figure 5: Occurrence of first and second augmentations of the water supply system, Post 1997 Base case, selected initial levels of storage.

To more clearly illustrate the differences between scenarios for initial storages in the desirable operating range ($S_0 \geq 60\%$), Figure 6 provides a bar chart comparing reliability costs. This highlights the different net present costs of maintaining a reliable supply associated with each scenario at a specific level of storage. In the Post 1997 realisations, at 70 per cent initial storage, reducing the lead time of the VDP expansion reduces the expected costs of supplying water by $104 million, or 32% of the anticipated costs, compared with the base case. This is a significant reduction in the anticipated costs associated with supplying water and suggests that there are considerable benefits associated with planning and preparing for the expansion of the water supply system. In addition, consideration of the potential option to use the North-South Pipeline more frequently than the base case results in $130 million of savings, or 40% of the anticipated costs. Utilising the desalination plant more frequently could result in savings of $47.5 million, or 15% of anticipated costs at 70% initial storages compared to the base case.

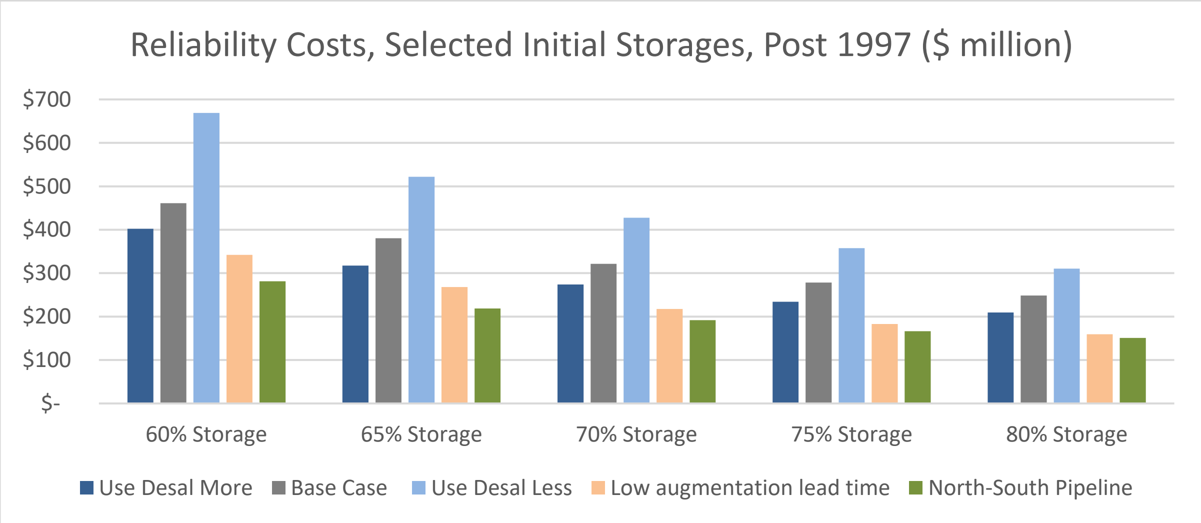

Figure 6: Reliability costs for alternative scenarios and selected initial storages, Post 97 inflows.

At lower levels of storage, the differences in scenarios is even more significant. At 60% initial storage, the scenarios examined suggest that the long-run costs of meeting expected demand could be reduced by $59 million, or 13% of the long-term costs, compared to the base case by operating the VDP at higher initial storages. Alternatively, by undertaking pre-planning for future augmentations, or considering the potential option to use the North-South Pipeline more frequently, the cost of maintaining a reliable water supply could be reduced by $119 million or $180 million, between 25 to 39%, compared to the base case. The benefits of alternative scenarios vary based on the initial storage. However, operating the VDP at higher initial storages reduces the expected costs at all levels of storage.

DISCUSSION

The scenarios examined suggest that the cost of delivering water to Melbourne could be further optimised and reduced by incorporating the cost of maintaining reliability into management decisions. From an economic perspective comparing marginal costs provides useful insights into specific decisions. Figure 7 shows the marginal value of water derived by calculating the gradient of the reliability cost curve with respect to initial storage expressed in ML.

The purchase cost of desalinated water for Melbourne under current arrangements varies between $560/ML and $610/ML (Table 3), depending on the order size, plus any pumping cost from Cardinia to Silvan, which is relatively small. The marginal cost of North-South transfer water is $199/ML in operating cost plus the opportunity cost of using water in the Goulburn system. The seasonal trade price has varied between $10/ML to over $700/ML over the last decade, and hence this opportunity cost, is highly variable and strongly dependent on storage levels in Lake Eildon. These results suggest that there is an economic case for the use of desalination for 1 January storages around 75% and below. An economic case can also be made for additional use of the North-South transfer but a more sophisticated decision making approach that accounts for prevailing trade prices would be required. There are also likely to be some infrastructure constraints on the full use of the North-South pipeline given the particular regions of Melbourne that can be supplied from Sugarloaf Reservoir. Further investigation of those constraints would also be needed.

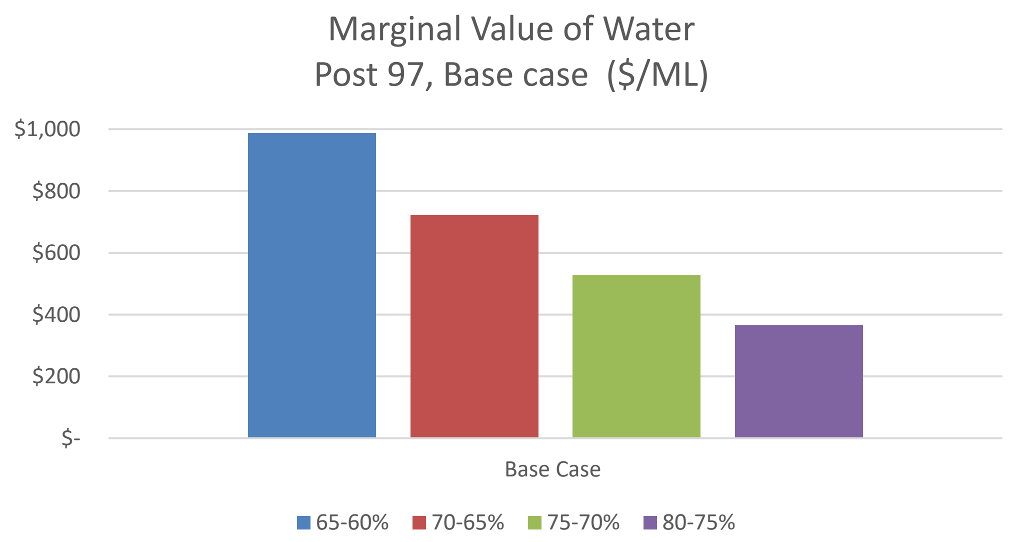

Figure 7: Marginal value of water in storage, Post 97 Base case, selected initial levels of storage.

More generally, this analysis demonstrates the important cost implications of interactions between short-term (operational) decisions and long-term (capital investment) decisions. If a purely short-term view were taken, the capital cost of system augmentation would be ignored, yet this is the single largest contributor to the overall reliability cost and a significant contributor to the marginal reliability cost. Indeed Figure 3 suggests that desalination operation contributes more to the marginal cost than the social costs of restrictions (the curve is steeper). Thus, cost estimates ignoring the capital cost would suggest that desalination should only be used at lower storage levels. In essence, economically sound short-term operational decisions need to account for impacts on long-term expected capital investment requirements. This comes about due to the combination of long system memory (Figure 2 shows this is approaching a decade for the Melbourne Water Supply System), the risks associated with variable inflows and the time lags involved in delivering capital investments in water supply augmentations.

One of the assumptions we have made in this analysis is to utilise stationary hydrologic realisations, informed by relatively recent conditions (i.e. like the last 20 years or like the last 40 years). This could be questioned from a climate change perspective. Figure 4 shows that costs are sensitive to the hydrologic scenario assumptions, with proportionally larger changes in expected costs at higher storage levels and larger absolute changes at lower storage levels. Given the main focus of the analysis is on operation, the near-term period is of most interest and hence distant climate change scenarios are of little relevance and any climate model scenarios for the coming decade would typically show small differences. Rather than relying on such scenarios, we believe a sensitivity approach where more extreme changes in hydrologic conditions are considered is more useful. This should consider two issues: are the policy recommendations materially affected by more extreme conditions and can the planned approach to system augmentation robustly meet the challenge of more extreme conditions. These can both be addressed by the analysis approach presented.

CONCLUSIONS

We have presented a framework for estimating the economic value of water in storage that accounts for both short-term operational costs and long-term capital costs. There is important interaction between the two and the overall cost of maintaining a reliable water supply can be quantified by incorporating the impacts of short-term operation rules with augmentation decisions that depend on maintaining sufficient storage to provide surety of supply. Here that surety of supply is defined by a minimum storage level coupled with knowledge of the lead time to deliver climate independent water supply augmentations. Using this approach, the benefits of operating the Victorian Desalination Plant to maintain a sufficient supply buffer are quantified. Straight forward operational scenario differences are shown to result in differences in expected costs of maintaining supply reliability of up to 40% of the base case cost or $140M. The framework could be used to make explicit the trade off between OPEX and CAPEX decisions and would allow for operational decisions to be optimised to reduce the combined operational, social and capital costs of maintaining supply reliability.

ACKNOWLEDGEMENTS

The project was funded by the Department of Environment, Water, Land and Planning, Melbourne Water, City West Water, South East Water and Yarra Valley Water. It was informed by the members of the Steering Committee including Richard Smith, Udaya Kularathna, Bruce Rhodes, Ian Johnson, Dominic Keary, and Stephen Sonnenberg. The Steering Committee was Chaired by Professor John Langford, University of Melbourne. While this project was informed by the Steering Committee, the findings contained in the paper are the responsibility of the Project Team and not the Steering Committee or the organisations they represent.

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BIOGRAPHY

Professor Andrew Western

Andrew Western has more than twenty-five years experience in catchment and waterway research, teaching and consulting. He has experience in the fields of hydrology, water resources, hydraulics and related disciplines and has worked as a researcher for the Centre for Environmental Applied Hydrology, Technical University of Vienna, The CRC for Catchment Hydrology and eWater CRC. He is now the Director of Infrastructure for the Melbourne School of Engineering at the University of Melbourne. Prof Western has expertise in field monitoring, physically-based and conceptual catchment and river modelling, catchment water quality, catchment analysis and remote sensing and has concentrated on integrating these areas to support catchment system understanding and management. He has undertaken major field programs in Australia and New Zealand investigating catchment behaviour.

Nathan Taylor

Nathan Taylor is undertaking a PhD at the University of Melbourne, having just finished a project quantifying the value of water in storage for the Department of Land, Water and Planning, Melbourne Water and the three retailers. He is the Home Advocacy and Advice Manager for the RACV, developing and advocating on policies relating to cost of living pressures as well as the built form of Victoria. He was the Chief Economist at CEDA where he was responsible for the organisations research and policy agenda, including research programs on Australia's Future Workforce, and Crisis and Opportunity: Lessons from Australian Water Reform. In the course of these projects, he has edited Australia's Unconventional Energy Options among other reports and authored the papers Insuring Australia's cities against drought, and, Urban Water Security Water Security: Water for the farm and City.

Professor John Langford

John Langford is an Honorary Professorial Fellow in the Department of Infrastructure Engineering at the University of Melbourne, Australia. He has a PhD in hydrology and hydraulics from the same University. His 35 year career in the Australian water industry spans an unusually diverse range of responsibilities including provision of city water services, irrigation and drainage, flood protection, and river basin management. He was manager in charge of operating Melbourne's water supply system, Chief Executive of Victoria's Rural Water Corporation, a Commissioner of the Murray Darling Basin Commission, and inaugural Executive Director of the Water Services Association of Australia. From his early career in forest hydrology research John has been a strong supporter of research focussed on improving water. John has been active in the initiation and implementation of complex water reforms including demand management of city water supplies, and the introduction of water trading.

Dr Mo Azmi

Mo Azmi is a professional water engineer with a demonstrated history of experiences across industry and research-based organizations; skilled in spatiotemporal analysis, sustainable water resources management, hydrology-hydraulic modelling, and environmental assessments. His M.Eng thesis highlighted the application of data-driven methods in long-term streamflow forecasting; while, his PhD dissertation focused on the drought analysis across Australia following a data-fusion based approach.