Appendix B

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Incorporating drought management planning into the determination of yield

Incorporating drought management planning into the determination of yield *

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SUMMARY: *The definition of system yield has undergone somewhat of a revolution in recent years with it no longer being acceptable to simply consider yield in terms of acceptability limits on the frequency and severity of restrictions. The reason for this change is it is "now expected that water utilities manage their water resources so that communities never run out of water" (Erlanger & Neal, 2005). The system therefore consists not only of the demands and infrastructure that exist, but also the emergency infrastructure and restriction strategy, referred to as a drought management plan (DMP), that must also exist to ensure an ongoing supply of water should a drought continue. The calculation of yield must now take into account the acceptability of reaching the various triggers in the DMP in addition to the previously used acceptability criteria relating to the severity and frequency of restrictions. A new methodology is presented in this paper to integrate performance of the DMP with a classical storage risk analysis to determine system yield, including an approach to present these two fundamentally different aspects of yield versus demand on a single diagram. The new methodology thereby allows users to simultaneously identify interactions between demand and the frequency and severity of restrictions, demand and the risks of activating drought management measures, and demand and the manageability of the DMP itself. Application of the new methodology is presented by way of a case study of the Hunter Water Corporation headworks system.*

1 INTRODUCTION

"Yield" is the average annual volume of water that can reliably be supplied by a water supply system (Erlanger & Neal, 2005) and is thus a fundamental measure of system capability. The assessment methodology for yield therefore has broad flow-on impacts, including assessment of the viability of all water supply and demand management options, development of long-term water resource strategies, calculation of scheme costs, and ultimately the development of capital programs.

The reason that yield is so critical to water resource planning is that for any investigation of options it is the yardstick by which both supply- and demand-side management strategies are compared against demand growth. These strategies can include anything from the construction of dams to the retrofitting of rainwater tanks, or new climate independent sources such as recycled effluent or desalinated seawater.

In 2005, the Water Services Association of Australia (WSAA) released a benchmark document (Erlanger & Neal, 2005) that outlined a framework for assessing system yield. This document described the various aspects of water supply system behaviour that a community or water utility should consider when developing their specific definition of yield. A key tenet of the WSAA document is that an urban water supply system, including its drought contingency measures, must be designed so that the system cannot run out of water. It therefore follows that in addition to being a function of commonly used level-of-service performance indicators relating to the expected frequency and severity of restrictions, yield is also a function of the capability of the drought management plan (DMP). Both aspects of performance (ie. level-of-service and the capability of the DMP) will decline with increasing demand for a given system.

This paper explores a new method to incorporate the acceptability of the DMP into the calculation of yield. A diagrammatical approach is developed for presenting these two fundamentally different aspects

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of yield on a single diagram, and it is hoped that this new approach will provide system managers with improved clarity when assessing how much water can be relied upon from their systems, ie. their yields.

The new methodology relies heavily on the existence of appropriate methods to assess headworks storage behaviour. These methods generally involve the simulation of reservoir storage levels with respect to demand and climate. They vary in sophistication and can be simple mass balance spreadsheet models using historic climate records through to sophisticated Monte Carlo models that utilise synthetic climate generation such as WATHNET (Kuczera, 1997) or REALM (Diment, 1991). It is not the intent of this paper to debate the level of sophistication in the simulation model that is required to achieve an accurate outcome.

The new methodology for incorporating the capability of the DMP into the calculation of system yield is presented in this paper against the backdrop of a working example. The example system is the headworks infrastructure operated by Hunter Water Corporation, which is used to supply potable water to a population of 500,000 people in the urban centres of the Lower Hunter, including Newcastle and Maitland.

In this particular example, the calculation of system performance is undertaken using an in-house FORTRAN model (SKM, 2003a) that employs the same multisite lag-one streamflow model as is used in WATHNET (Kuczera, 1997) to generate synthetic rainfall and streamflow data. Annual probabilities are derived using 20,000 replicates of climate, with each replicate being 25 years in length. Results for the first 6 years of each sequence are discarded to minimise start-up bias. Each assessment of annual probability is thus derived from storage performance using a total of 380,000 simulated years.

Other pertinent aspects of the modelling of the example system include:

- Surface water storage behaviour is calculated using a daily time-step.
- Groundwater storage behaviour is calculated using a monthly time-step model (Berghout, 2002).
- The models used to assess system performance are run with a constant "nominal demand" (ie. zero growth).
- The demand function within the simulation model runs at a monthly time-step, with demand in any particular month being calculated as a function of the time of year, the level of restriction in force and climate. This means that the simulated demand in any given month can be considerably higher or lower than the "nominal demand" due to the level of restriction and climate. Demand sensitivity to climate and time of year is reduced relative to the level of restriction (ie. demand is considered to be less elastic when more severe restrictions are in force).

The layout of this paper is as follows. Firstly a structure is developed to define and measure acceptability of DMP performance relative to demand. This is followed by development of a compatible structure to measure the frequency and severity of restrictions against demand, and then an explanation of how this can be integrated with DMP performance to calculate system yield. The paper finishes with the presentation of a case study to demonstrate how yield can be determined using the new methodology.

2 DEVELOPING ACCEPTABILITY CRITERIA FOR DMP PERFORMANCE

The WSAA *Framework for Urban Water Resource Planning* states up front that:

> *It is expected and understood that water utilities manage their water resources so that communities never run out of water. As a bare minimum, water utilities need to define what the minimum supply requirement is and then ensure that they always have enough water to meet it. Minimum supply volume will vary depending on the community involved and the consequence of minimising supply.* (Erlanger & Neal, 2005, pp. 6)

There are a number of important messages bound up in this statement. Firstly the statement is presented in absolute terms – there is no acceptable probability of running out – the system must be designed to ensure ongoing supply. However, while it is definitive with regards to ongoing supply, the WSAA framework does allow for the supply rate to be reduced by way of a water restriction policy down to the "minimum supply" required for the community.

The DMP is the set of contingency measures that are activated during times of drought to ensure the ongoing supply of water. These contingency actions can include both demand management initiatives (water usage restrictions), which range from minimal first level restrictions through to severe restrictions required to achieve the "minimum supply requirement", as well as emergency water supply schemes. Any water supply system that relies on water sourced from natural systems will require some form of DMP that includes alternative water source options, because otherwise the system would carry some level of risk of running out of water. In order to satisfy the WSAA framework, the DMP must exist and it must be workable (ie. it must be realistic).

A DMP can be considered to be workable if it will ensure the ongoing supply of water in any conceivable drought sequence, which should include potential climate change impacts. In order for the DMP to be workable, there must be sufficient time in the DMP to plan, approve, construct and commission any alternative water supply schemes, and sufficient community and government backing of the plan to ensure that approvals will be achieved in the planned timeframes when triggered. This level of workability can be hard to achieve due to the long lead times for climate independent emergency supply schemes such as construction of major desalination or sewerage recycling plants.

In addition to the problem that a long lead time can render a DMP unworkable simply because the system can drop from full to empty in a shorter period of time, there is also the problem that decisions set out in the plan may not be made when required. There is a very real risk for a contingency measure with a long lead time that the risk of requiring it is so low at the point in time when the decision should be triggered that funding will not be forthcoming. It may be possible in some circumstances to improve the feasibility of a DMP by reducing the lead times of contingency measures through pre-work. This pre-work could include actions such as design work, pre-approvals, purchasing of sites or even partial construction.

Assuming that lead times have been correctly estimated and that a technically feasible DMP can be developed, assessing the workability of the DMP will largely be driven by whether or not the community and authorities could be expected to enact the plan steps in a timely fashion should they ever be triggered. Arguably the likelihood of the steps being enacted will be related to the severity of drought that is being experienced when called upon, and the environmental and financial impact of making the decisions. For example, it would be difficult for an authority to justify expenditure and environmental impacts for DMP actions triggered during a 1-in-1-year drought event that everyone in the community knows has never been a problem in the past.

The setting of acceptability criteria for the risk of triggering the DMP actions will be site and community specific, as it will depend on the level of risk that regions are willing to accept and the scheme specific costs associated with the contingency supply options. Regardless of the site, however, there will be a threshold at which demand exceeds the locally set acceptability criteria for performance of the DMP. In order to identify the threshold, a method is required to assess DMP performance as a function of demand.

3 MEASURING DMP PERFORMANCE

For a particular system, the performance of the DMP is related to the demand on the system. The higher the demand on the system, then the faster storage can fall during a drought, and the earlier that steps in the DMP would need to be implemented – that is, the DMP triggers for a particular system would need to be set higher for higher system demands. The calculation of required trigger levels as a function of demand is relatively straightforward for a given demand and climate sequence. The triggers are selected to satisfy scheme lead times, minimise costs and ensure the ongoing supply of water.

Figure 1 provides an example of a relationship between DMP triggers and demand. In this example, the DMP trigger names (ie. 36 month and 48 month) refer to the points in time 36 months and 48 months prior to the natural system potentially running out of water in an ongoing drought sequence. These two timeframes have been selected on the basis that they represent key financial and environmental milestones in the DMP for the example system.

The real indicator of DMP performance, however, must be a measure of the risk of reaching the triggers as a function of demand, not the trigger values per se. Once the relationship between demand and trigger levels has been established, the risk of reaching the triggers can be assessed separately from some sort of system performance analysis for the particular

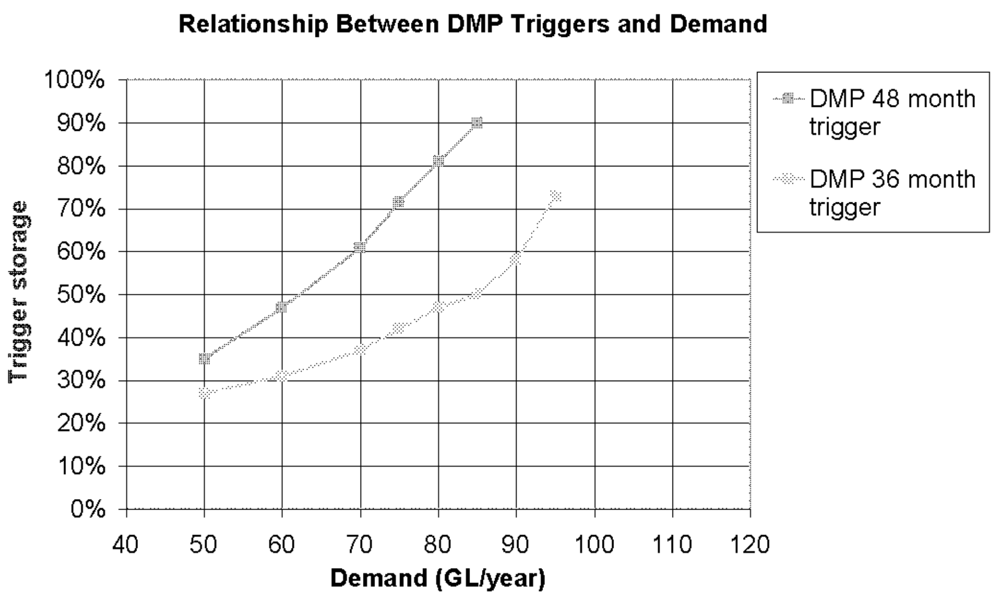

Figure 1: Relationship between demand and lead times in DMP.

level of demand. The higher the demand, the quicker the system can deplete and the longer it takes to recover, thus increasing the risk of dropping to any particular storage level. The risk of reaching DMP triggers therefore grows more rapidly with increasing demand than one might initially think due to the combined influence of the trigger levels rising and increasing risk of dropping to any particular level.

Figure 2 contains a plot showing an overlay of an analysis of system performance (in this case the risk of reaching particular storage levels) as a function of demand on top of DMP triggers as a function of demand. The annual probabilities of reaching particular storage levels can be derived as a function of demand by running a headworks simulation model such as WATHNET (Kuczera, 1997) or REALM (Diment, 1991).

The crossover points between the trigger lines and the storage risk lines in figure 2 indicate the level of demand that can be met for a given risk of reaching a given DMP trigger. For example, in this system the crossover between a 1-in-100 storage level and the 48-month DMP trigger occurs for a demand of around 68 GL/year. In other words, when the demand on this particular system is 68 GL/year for a specific set of water restriction and alternative supply measures as modelled, the annual risk of reaching the 48-month trigger in the DMP is around 1-in-100. The 48-month trigger point in this example happens to be around 58% for this particular level of demand. Six crossover points between DMP triggers and frequencies are presented in this example, any of which could potentially be used as the basis for setting an acceptability criteria for DMP workability. The six potential acceptability criteria identifiable in figure 2 are summarised in table 1.

4 YIELD CRITERIA RELATING TO LEVEL-OF-SERVICE

Level-of-service acceptability criteria are generally based on the frequency, severity and duration of water restrictions. This type of criteria are described in Erlanger & Neal (2005) and have been widely used around Australia (eg. ACTEW, 2004; SKM, 2003b; HWC, 2003). The reason for having these criteria as part of the definition of yield is that these criteria set acceptability thresholds for the community impacts associated with water use restrictions.

System performance can be assessed against these criteria by calculating the frequency of reaching restriction triggers as a function of demand and the percentage of time spent below restriction triggers as a function of demand. Again these calculations are carried out by running a headworks simulation model.

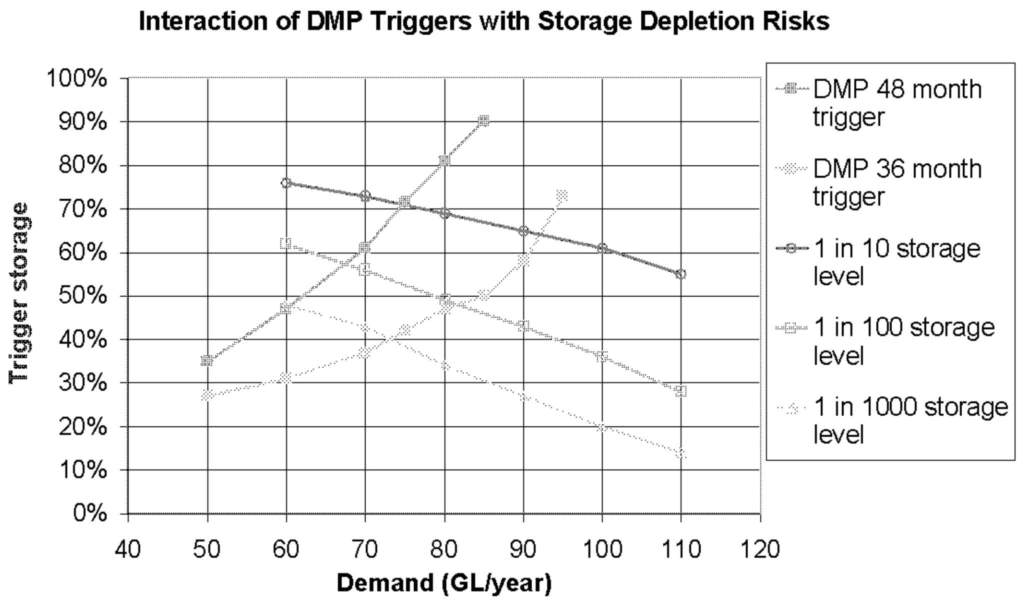

Figure 2: Interaction of annual storage level risks with DMP triggers as a function of demand.

Table 1: Matrix of limiting demand for six potential DMP acceptability criteria.

Acceptability criteria (annual risk) \ DMP trigger	DMP 48-month trigger	DMP 36-month trigger
1-in-10 year frequency	75 GL/year	92 GL/year
1-in-100 year frequency	68 GL/year	82 GL/year
1-in-1000 year frequency	61 GL/year	74 GL/year

An example of how level-of-service criteria can be assessed against demand is provided in figure 3. In this example, the level-of-service criteria state that the system should not be in restriction more than 5% of the time and that the annual risk of entering restrictions should not exceed 1-in-10. If the restriction trigger is set at 60% (the same value as used in the DMP analysis), then the maximum rate of supply that meets the 5% of time and 1-in-10-year criteria can be derived from figure 3. In this particular example, the 5% of time criterion is more limiting than the frequency of restrictions criterion. The maximum rate of supply that meet each criterion are summarised in table 2.

5 INTEGRATING DMP AND LEVEL-OF-SERVICE CRITERIA

Since the performance of both the DMP and the level-of-service criteria have been derived as functions of demand, they can be brought together on a single diagram, an example of which is shown in figure 4.

There is considerable value in bringing all the information together onto a single diagram like figure 4. This diagram effectively summarises the supply risks relative to demand for a specific DMP strategy and headworks system, making it a powerful tool for incorporating drought management planning into the assessment of system yield.

Once the information has been brought together, an acceptability criteria needs to be set for the DMP. In this example, the water supply authority ultimately chose an acceptability criterion for reaching the 48-month trigger as being an annual 1-in-100 risk on the basis that there are a number of actions that should be triggered at the 48-month point in the plan that the community would strongly oppose unless it could be accepted as a genuine emergency. A 1-in-100 drought event was considered to be sufficiently rare that its impacts would be well recognised broadly in the community by the time difficult decisions in the drought planning process would need to be made. In the above example, the "yield" of the system with the DMP as modelled is the maximum rate of supply that meets the DMP criterion, as well as the two level-of-service criteria. This result is shown in table 3.

6 APPLICATION OF THE METHODOLOGY

Application of the methodology is briefly described for the purpose of demonstrating practical application and to highlight some useful insights that can be gained through its application. While a number of real-life scenarios are presented, it is not the intention of the author to in any way suggest that these details form a robust analysis of available options for the particular region. The examples are derived from the urban water supply system for the Lower

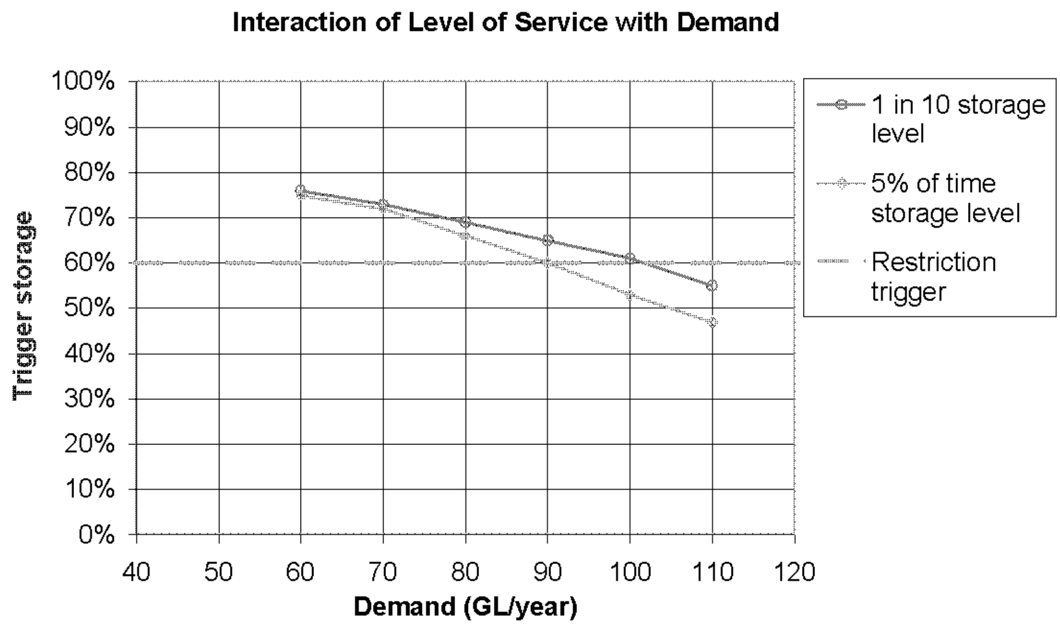

Figure 3: Relationship between demand and level-of-service.

Table 2: Matrix of limiting demand for two level-of-service acceptability criteria.

Acceptability criteria	Limiting demand with restrictions triggered at 60% storage
1-in-10-year frequency of entering restrictions	101 GL/year
5% of time in restrictions	90 GL/year

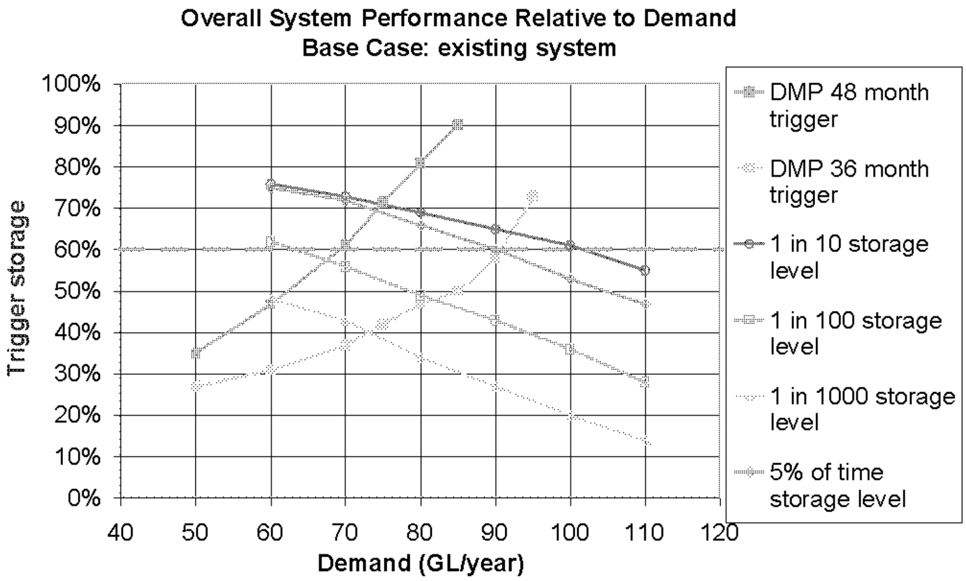

Figure 4: Combined graphical representation of DMP performance and level-of-service performance against demand.

Table 3: Summary of acceptability criteria for the example system.

Performance measure	Acceptable annual risk	Maximum demand that satisfies criteria
1. Acceptable annual risk of reaching the DMP 48-month trigger	1-in-100	68 GL/year
2. Acceptable frequency of entering restrictions	1-in-10	101 GL/year
3. Acceptable proportion of time spent in restrictions	5% of time	90 GL/year
Resulting yield that meets all three criteria		**68 GL/year**

Hunter, which supplies reticulated potable water to a population of around 500,000 people.

Three types of scenario are presented to demonstrate a range of yield analyses. The three scenario types to be analysed are:

1. an analysis of an existing system (the base case)
2. base case + a 25 GL/year constant climate independent source (eg. desalination or recycling)
3. base case + a new 250 GL or 450 GL on river storage.

6.1 Base case yield analysis

The diagrammatic representation of level-of-service and DMP risks for the base case has already been covered as the base case was used for the example system earlier in this paper. The diagram of risks is shown in section 5 in figure 4, with the resulting yield summarised in table 3. The base case yield is assessed as being around 68 GL/year.

Prior to adopting the new methodology, the water authority did not include any drought management criteria in its assessment of yield. In fact the two criteria used to assess yield were the same as the two level-of-service criteria that have been retained. Prior to this assessment, yield was estimated to be around 90 GL/year, with proportion of time in restrictions being the governing criteria.

Using the diagrammatic approach presented in figure 4 it can be seen that if demand had been allowed to grow to 90 GL/year, triggering of the works at the 48-month trigger would have been a dead certainty. The actual demand on the system is currently around 73 GL/year, which while short of the previous assessment of yield, is still substantially higher than the new assessed yield. An augmentation of some form is therefore deemed necessary for the reasons presented earlier in this paper.

6.2 Base case + 25 GL/year constant source

A constant, climate-independent source could be provided by construction of a desalination plant or, if sufficient sewerage is available, through construction of a major wastewater recycling scheme. Such schemes have appeal because from a climatic variability perspective there is little risk to supply. Indeed there are many circumstances where reasons to proceed with a climate-independent source augmentation are compelling.

While this was not ultimately the preferred option for a range of cost and environmental reasons, the analysis did correctly highlight the benefit of a climate-independent source. While the augmentation was sized at 25 GL/year, the yield (incorporating DMP criteria) was found to increase by around

32 GL/year to around 100 GL/year. The reason for this increase being higher than 25 GL/year is that yield is assessed in terms of unrestricted demand. The available length of time in a drought sequence, which governs the location of the 48-month trigger, is a function of the relativity between available supply and restricted demand for much of the drought sequence. The relative benefit of the 25 GL/year climate independent source thus increases substantially during drought sequences. The system performance characteristics of this option are summarised in figure 5.

6.3 Base case + 250 GL or 450 GL new dam

One of the characteristics of the base case system is that while streamflow is relatively reliable, storage can deplete rapidly during a drought. It is this characteristic that leads to relatively poor drought performance compared with level-of-service performance, and this in turn drives down yield. This characteristic can to a large extent be addressed through the provision of greater storage, which is investigated in this option.

Given the location of the site in question, a new storage in this example would actually end up having the dual role of catching additional water, as well as providing the increase in storage required to improve drought performance. The risk performance of this pair of options is shown diagrammatically in figures 6 and 7.

Comparison of this pair of options provides an interesting perspective of how the risks behave with different size storage options on the same river. If considering the level-of-service criteria alone, there is very little difference between the two options, with both being able to supply around 125 GL/year. Presumably this is the case because the level-of-service criteria are driven more by the reliability of inflows on average, rather than performance during drought. There is a much greater difference in yield, however, when drought performance is incorporated into the calculation of yield. The system yield with a new 250 GL storage is estimated to be around 100 GL/year, and with a new 450 GL storage, is estimated to be around 120 GL/year. This difference, which is primarily driven by an acceptability criteria relating to the risk of reaching the 48-month trigger in the DMP, makes good sense – a larger storage, provided that it can fill between droughts, will provide a greater buffer against running out of water should a drought commence. In this example, it is arguable that the methods presented in this paper have been successfully used to incorporate drought management planning into the determination of system yield.

7 CONCLUSION

System yield is the amount of water that can reliably be supplied by a system. While in the past this could have been achieved by not putting customers into restrictions too frequently, a much more rigorous approach is now required, because as a society it is known that more severe droughts can occur and that they should be planned for. This does not necessarily mean that we need to abandon climate-dependent water supply systems, but that there is a need to ensure that these systems can be coupled with effective drought management strategies to ensure ongoing water supply in any circumstance. Indeed, such schemes can still prove to be cost-effective water supply options under specific circumstances.

The approach to assessing yield presented in this paper brings together the two fundamental aspects of system performance that are driven by demand. These are the manageability of the system during ongoing drought, and the level-of-service that the system can achieve in terms of the frequency and

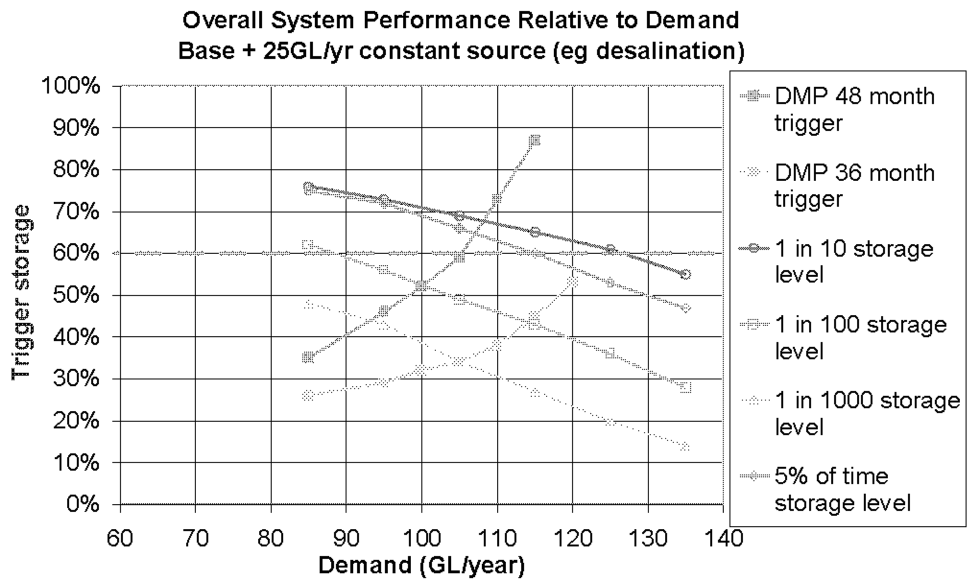

Figure 5: Performance of base case + 25 GL/year source.

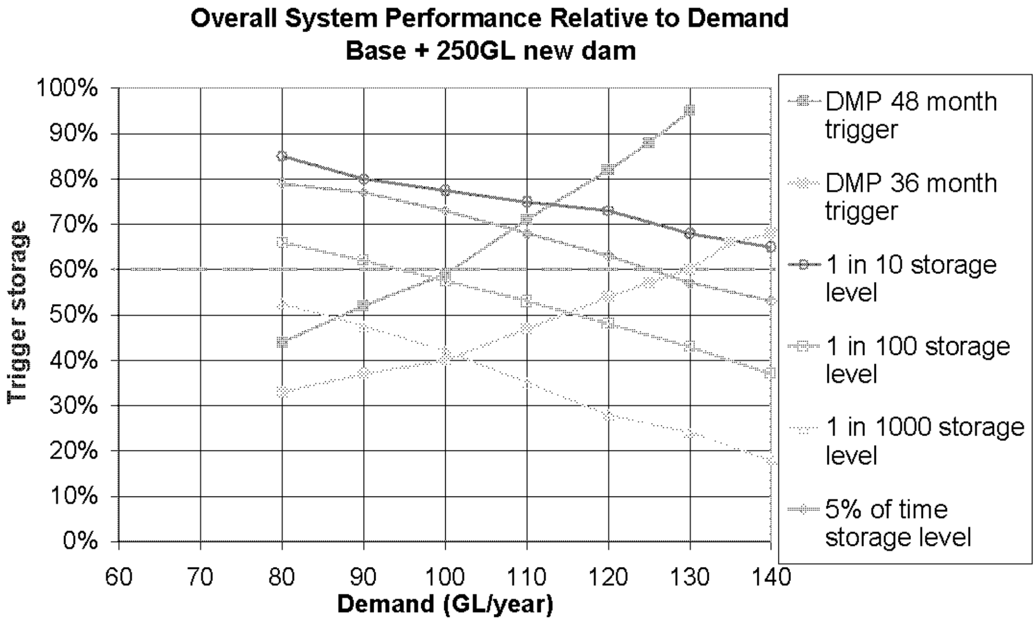

Figure 6: Performance of base case + 250 GL dam.

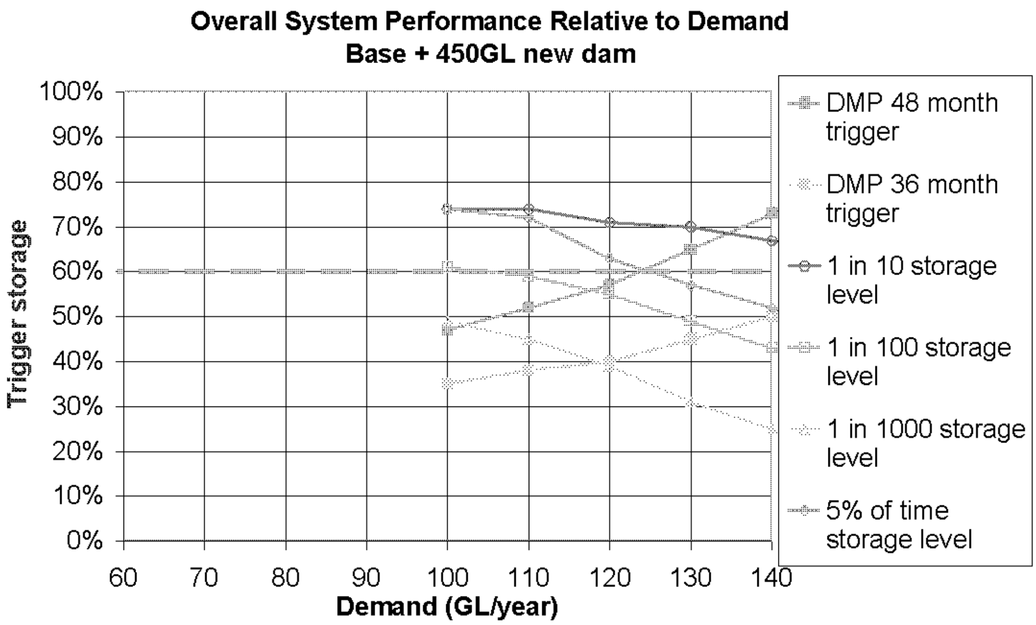

Figure 7: Performance of base case + 450 GL dam.

duration of water restrictions. A new diagrammatic approach is presented that allows these two aspects of system performance to be assessed simultaneously for any given demand management or supply augmentation strategy.

The approach that is presented has been successfully used by Hunter Water Corporation to assess a number of water supply and demand management options. It was found that the new method correctly identifies the benefits of storage capacity in terms of improved drought time performance, and the benefits of streamflow reliability in terms of minimising the frequency and duration of water use restrictions. The approach also appropriately identifies significant benefits to both aspects of system performance that can be achieved by introducing climate-independent water sources. Indeed, given that yields are generally expressed in terms of unrestricted demand, the yield benefits of climate-independent sources were found to be higher than the nominal capacities of the schemes analysed due to their ability to cater for an increasing portion of the demand base when restrictions are imposed during drought sequences. In an independent review of the approach that was commissioned by the Independent Pricing and Regulatory Tribunal of NSW, SKM (2008) found that the Hunter Water "yield estimates are considered to be reasonable and robust".

Following introduction of this new approach to determining yield, Hunter Water has de-rated the yield of its existing system by around 25%, resulting in a yield shortfall when compared with demand

(HWC, 2007; 2008). Hunter Water is now progressing the planning and approval process for a large dam that will not only address this shortfall, but will also satisfy demand growth for at least another 50 years.

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