DID WE GET WHAT WE PAID FOR? COMPARING DESIGN ESTIMATES TO REAL VOLUME USAGE FOR STORMWATER HARVESTING

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Abstract

In 2009 Council commenced a stormwater harvesting monitoring program that records used volumes of water for irrigation and volumes of water in storage. This has allowed a detailed assessment of the accuracy of water balance models used as part of the design for two stormwater harvesting systems, Barra Brui sports field and Tryon Oval 2.

Over the course of one year, the volume of reused stormwater was lower than what was assumed during the design phase for both systems. This was partly due to the fact that the irrigation demand was lower than what the model estimated. This would suggest that the irrigation management strategy adopted by Council estimates an evapotranspiration of approximately 30% of pan evaporation rather than 70% which was assumed in the initial modelling. Both systems assessed as part of this case study used less stormwater for irrigation compared to what was anticipated during design. They did however provide in excess of the modelled security of supply due to a more conservative irrigation regime. Consequently, both systems provided volumes in excess of what was required to satisfy current irrigation regimes

The lack of widely adopted industry guidelines for water balance modelling in stormwater harvesting applications causes a number of problems when seeking to compare projects. A model that grossly overestimates irrigation requirements will result in a much higher volume of reused water. This can lead to the assumption of a higher return on investment based on a lower cost per kL for the system.

This case study highlights the need for industry guidelines in order to allow fair comparison between projects (for example as part of grant applications that may be assess against cost per kL) as well as informing more realistic designs.

Introduction

Stormwater harvesting is becoming a popular strategy to mitigate the impact on water availability in urban irrigation caused by droughts, climate change and population growth. During the design of stormwater harvesting systems, designers often rely on water balance models to inform the process, providing estimates of the volume of stormwater that can be reused. These models in turn commonly rely on historic rainfall data and estimates in irrigation demand and harvestable yield. The overall objective is to optimise storage sizes and other infrastructure and thus provide best value for money.

In Ku-ring-gai Council, located 14 km to the north of Sydney, the popularity of sport across the local government area (LGA) has increased. With this the demand and consequent wear of the turf is beyond what is sustainable in terms of providing a sound playable surface. Reconstruction of the sports field soil profile and providing irrigation are two important mechanisms to improve the condition and use of many sporting venues. In response, Council has adopted a program that will see 12 stormwater harvesting systems implemented at local sports fields in combination with oval upgrades over a period of eight years. Six systems have been constructed with another two to be completed by the end of 2010.

For each site, the design has followed a similar process. After assessing options at each site a water balance model is built. The model is used to evaluate levels of water security from a supply and demand perspective in response to different diversion configurations and storage volumes. Security of supply is expressed as the percentage of total annual irrigation demand by volume that can be provided by the stormwater harvesting scheme.

A lack of broadly accepted commercial water balance models has led Council, as well as many consulting engineers, to develop their own in-house products. For clients such as local government who have many projects and utilize a number of consultants this has meant the comparison of model outputs has not been possible due to variations in methods and assumptions. The experience of Ku-ring-gai Council has found the majority of models are built using Microsoft Excel. The input and the general theories on which the models are based are usually provided, however due to concerns about intellectual property, actual models are not revealed as part of the final report and analysis.

The supply side of models usually relies on parameters derived from event based peak flow modelling. This is subject to the judgment of individual engineers and modellers. Demand is subject to the knowledge and understanding of a range of variables such as soil condition, turf type, irrigation techniques, climate and operational practices. The outcomes of both supply and demand analyses have direct impact on yield and required storage volumes in turn influencing eventual viability, capital and ongoing costs of projects.

In most cases there is no data available to verify modelling results. This impacts on the robustness of the model and inturn the prioritization processes to deliver capital works against water conservation and open space strategies.

Previous research done by Ku-ring-gai Council has shown that the supply side of water balance models in some cases significantly overestimates the runoff volumes generated during storm events (Jonasson et al 2007, Jonasson et al 2009). This obviously impacts on the storage volumes and design. The occurrence of base flow (as well as access to this water) at a stormwater harvesting site may also significantly impact on required storage volumes.

On the demand side of water balance models for stormwater harvesting, Ku-ring-gai Council has had very little data available to verify modelling assumptions and have relied on modelling of water storage in site soils for this component. In 2009 Council commenced a monitoring program that recorded actual volumes of water for irrigation and volumes of water in storage. Where mains backup was used, this was also monitored. This has allowed a detailed assessment of the accuracy of water balance models used as part of the design.

This paper compares design calculations undertaken as part of the design phase of two stormwater harvesting systems, one with subsoil irrigation and one with pop-up sprinklers, with monitoring data of tank volumes and irrigation volumes for one year.

Background

Modelling done as part of the design of stormwater harvesting is normally done by the designer. When external consultants prepare a design for Council, Council also prepare their own water balance models as verification. Where the system design is done by Ku-ring-gai Council modelling is usually conducted using a water balance model developed in-house that incorporated 64 years of daily rainfall data from Turramurra between 1936 to 2000 (Australian Bureau of Meteorology site 066158). The model incorporated soil water holding capacity and losses from storage through evapotranspiration (daily pan evaporation data for Sydney Observatory Hill, located approximately 14 kilometres from the LGA is used for calculations) and deep soil infiltration to determine irrigation demand. Above ground irrigation system (sprinklers) or subsoil irrigation systems can be modelled.

This paper provides a case study of two sports fields:

1. Barra Brui sports field, designed in 2004 and built in 2005. Irrigation by overhead popup sprinklers. Water balance modelling was carried out both by an external consultant responsible for the detailed design of the system and later by Council. The system is equipped with mains water backup however this has been disabled.
2. Tryon Oval 2, designed in 2006 and built in 2007. Irrigation by subsoil irrigation system. Water balance modelling was carried out both by an external consultant responsible for the detailed design of the system, and by Council.

The monitoring system used at these sites is web based and provides data on stormwater in storage and rates and volumes of water used for irrigation.

Method

Monitoring data from each site was collected from September 2009 to September 2010.

Rainfall runoff relationship

In order to assess the rainfall runoff component of the water balance models, rainfall data was collected from the Bureau of Meteorology (BoM 2010). As the model used by Council uses daily time steps, daily rainfall data was collected from the sites closest to each stormwater harvesting system. For Tryon Oval 2 this was Castle Cove (station number 066080), located 2.4km from the sports field, and for Barra Brui this was St Ives (station number 0660206), located 3.4km from the site.

The change in volume of water in storage from the monitoring can then be compared to the fluctuation in stored volume that forms part of the water balance model, allowing an assessment of the rainfall-runoff relationship for the local catchment. Different catchment scenarios were modelled in order to obtain a reasonable fit between the modelling results and the monitoring data.

Irrigation water usage

Irrigation demand can be calculated by estimating the amount of water being lost from the soil from evapotranspiration. There are a few methods used in Australia eg. *Code of Practice Irrigated Public Open Spaces* (SA Water), *Efficient Irrigation: A Reference Manual for Turf and Landscape* (University of Melbourne) however they adopt a similar strategy. Evapotranspiration loss is calculated as a percentage of pan evaporation loss and the following irrigation demand may or may not also include a stress factor as well.

The daily water balance model used by Council estimates the irrigation demand through modelling of the soil water holding capacity and losses from storage through evapotranspiration and deep soil infiltration. Evapotranspiration is calculated as being a percentage of pan evaporation (data from Sydney Observatory Hill used), and also varies with the season. Council's model assumes evapotranspiration to be between 56% and 70% of pan evaporation, depending on season. This is considered reasonable for a sports field that aims for vigorous growth (Connellan 2002).

Irrigation of a set depth of water is initiated once a set threshold value of water stored in the soil is met. Water soil storage, watering threshold and irrigation depth can be varied in the model. For Ku-ring-gai Council the modelled irrigation demand is approximately 500mm/yr, but this can vary depending on irrigation type and soil properties. The estimated volumes of reused stormwater for systems completed to date have been calculated to be in the range of 2,000 to 4,000 kL per year per system, depending on the area to be irrigated.

Real irrigation patterns and volumes have been recorded as part of the monitoring, and both irrigation pattern and volumes are compared to modelling estimates obtained during design.

Results

Modelling results and test of modelling scenarios

Barra Brui Sports Field

Results from water balance modelling for Barra Brui done by an external consultant and by Council are presented in Table 1.

Table 1. Modelling result as part of design of irrigation demand and system performance, Barra Brui sports field, St Ives.

	Consultant	Council
Annual irrigation demand (mm/yr)	918	506
Annual volume of resued stormwater (kL/yr)	9,000	3,900
Storage volume (kL)	250	250
Security of supply	83%	75%
Years of rainfall data used in modelling	20	64

The differences between the models are largely due to differences in how the watering demand was calculated, with the consultant using a much higher watering demand. The consultants also modelled a larger contributing catchment for runoff generation.

As part of this case study, the Council model was amended to include local rainfall data from St Ives for the year September 2009 to September 2010. With all other modelling parameters left unchanged the model returned a security of supply in the order of 83% with a reuse volume of 4,400kL per year. The annual irrigation demand for this period was modelled to be 540mm/yr.

However, the model assumes a storage volume of 250kL, as this is the total volume of the tank installed at the site. In reality, only about 113kL is available for storage due to the pump sump at the bottom and a leak at the top half of the storage. The irrigated area is also smaller than what was assumed during the design phase, and is 7,500m2 compared to 9,800m2 as assumed in the initial modelling.

If the model was changed to reflect the actual conditions, the security of supply as modelled in the Council model is approximately 70% with a reuse volume of 2,800kL per year. Irrigation demand is left unchanged at 540mm/yr. Impact on the consultant's model could not be assessed as only the design modelling results were made available.

However, it can be argued that a Council sports field can tolerate less than vigorous growth which will reduce the irrigation demand and thus the volume of reused water (IPOS 2008). If the model was run with a reduced evapotranspiration loss of between 24% and 30% of pan evaporation, the security of supply would be in the order of 93% with a reuse volume of 490kL per year. The irrigation demand for the period from September 2009 to September 2010 would be around 70mm.

The model initially assumed irrigation of 10mm per cycle. In reality, irrigation was found to be in the order of 2mm per cycle, less than what is ideal. Both these scenarios were therefore modelled. It should be noted that 2mm of irrigation is lower than the calculated daily evapotranspiration loss during summer if this is modelled as 70% of pan evaporation.

Figure 1 shows the results of the different modelling scenarios (modelling the storage volume as 113kL) compared to actual irrigation patterns. Volumes of water used for irrigation are shown as accumulated volumes, using local rainfall data from September 2009 to September 2010.

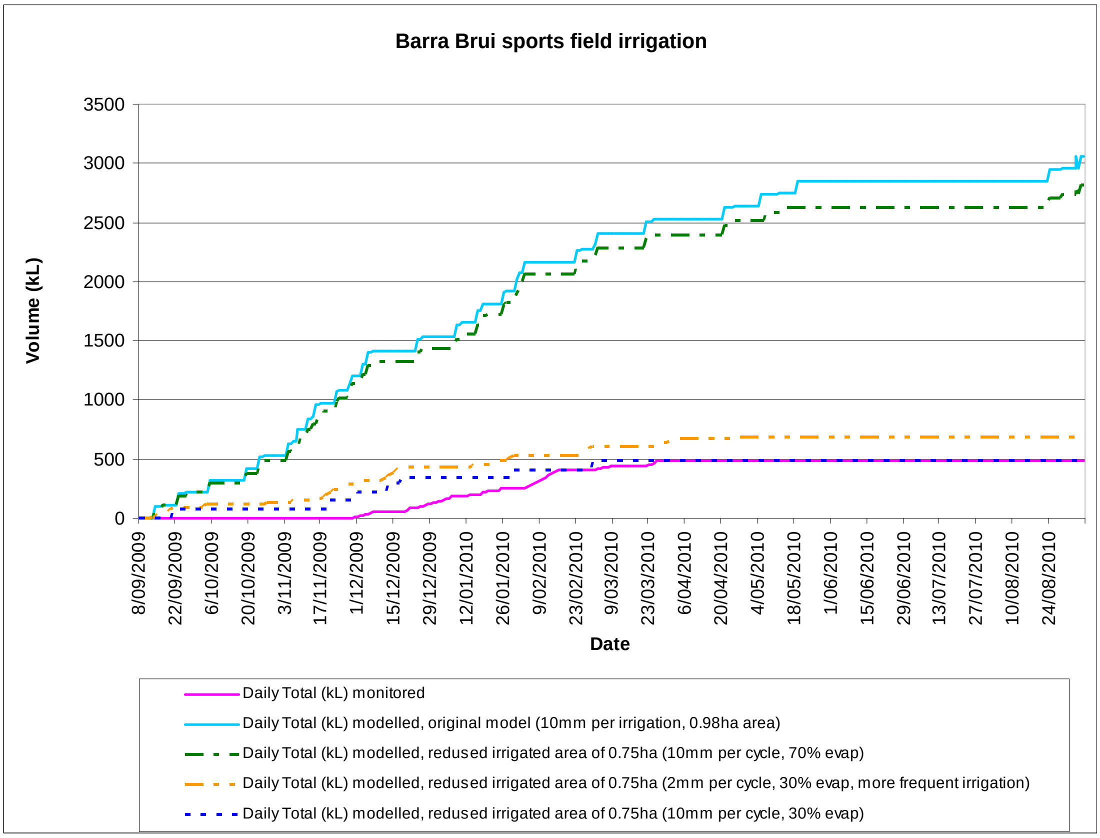


Figure 1. Barra Brui irrigation modelling (September 2009 – September 2010)

The original model (with a revised storage volume of 113kL) estimates the volume of reused stormwater to be 3,060kL with periods of the storage being empty, reducing the volume of reused water. The real volume of water used for irrigation during the modelled period was 490kL, with the storage never being critically depleted.

<u>Tryon Oval 2 sports field</u>

Results from water balance modelling done by an external consultant and by Council are presented in Table 2.

Table 2. Modelling result as part of design of irrigation demand and system performance, Tryon Oval 2 sports field, Lindfield.

	Consultant	Council
Annual irrigation demand (mm/yr)	332-495	444
Annual volume of reused stormwater (kL/yr)	2,300-3,900	2,500
Storage volume (kL)	500	500
Security of supply	72-86%	70%
Years of rainfall data used in modelling	12	64

The consultant modelled two different evapotranspiration scenarios for subsoil irrigation, the reason for the variation in these results. The consultants also modelled a smaller contributing catchment for runoff generation.

In order to make a comparison to the monitoring results, the Council model was then amended as part of this case study to include local rainfall data from Castle Cove for the year September 2009 to September 2010. With all other modelling parameters left unchanged the model returned a security of supply in the order of 66% with a reuse volume of 2,900kL per year. The annual irrigation demand for this period was modelled to be 548mm/yr.

However, the model assumes a storage volume of 500kL, as this is the total volume of the tank installed at the site. In reality, only about 376kL is available for storage due to sump at the bottom and the overflow structure at the top. The irrigated area is also smaller than what was assumed during the design phase, and is 5,000m2 compared to 8,000m2 as assumed in the initial modelling. The final contributing catchment was also found to be slightly smaller than what was assumed in the Council model during design, with a reduction in impervious catchment from 0.25ha to 0.22ha.

If the model was changed to reflect this, the security of supply was modelled in the Council model as being approximately 75% with a reuse volume of 2,100kL per year. Irrigation demand is left unchanged at 548mm/yr. Impact on the consultant's model could not be assessed as only the design modelling results were made available.

As was the case for Barra Brui, the model initially assumed a deeper irrigation depth per cycle than what monitoring would indicate. For Tryon Oval 2 the irrigation depth was initially modelled as 4mm per cycle. In reality, irrigation was found to be in the order of 2.5mm per cycle. Both these scenarios were therefore modelled. It should be noted that even though Tyron Oval 2 utilises subsoil irrigation (with a higher efficiency than pop-up sprinklers) 2.5 mm of irrigation is lower than the calculated daily evapotranspiration loss during summer if this is modelled as 70% of pan evaporation.

As for Barra Brui, it can be argued that a Council sports field can tolerate less than vigorous growth which will reduce the irrigation demand and thus the volume of reused water (IPOS 2008).

If the model was run with a reduced evapotranspiration loss of between 24% and 30% of pan evaporation, a reduced impervious catchment and irrigation depth of 2.5mm per cycle, the security of supply would be 100% with a reuse volume of 620kL per year. The irrigation demand for the period from September 2009 to September 2010 would be around 132mm.

Figure 2 shows the results of the different modelling scenarios (modelling the storage volume as 376kL) compared to actual irrigation patterns. Volumes of water used for irrigation are shown as accumulated volumes, using local rainfall data from September 2009 to September 2010.

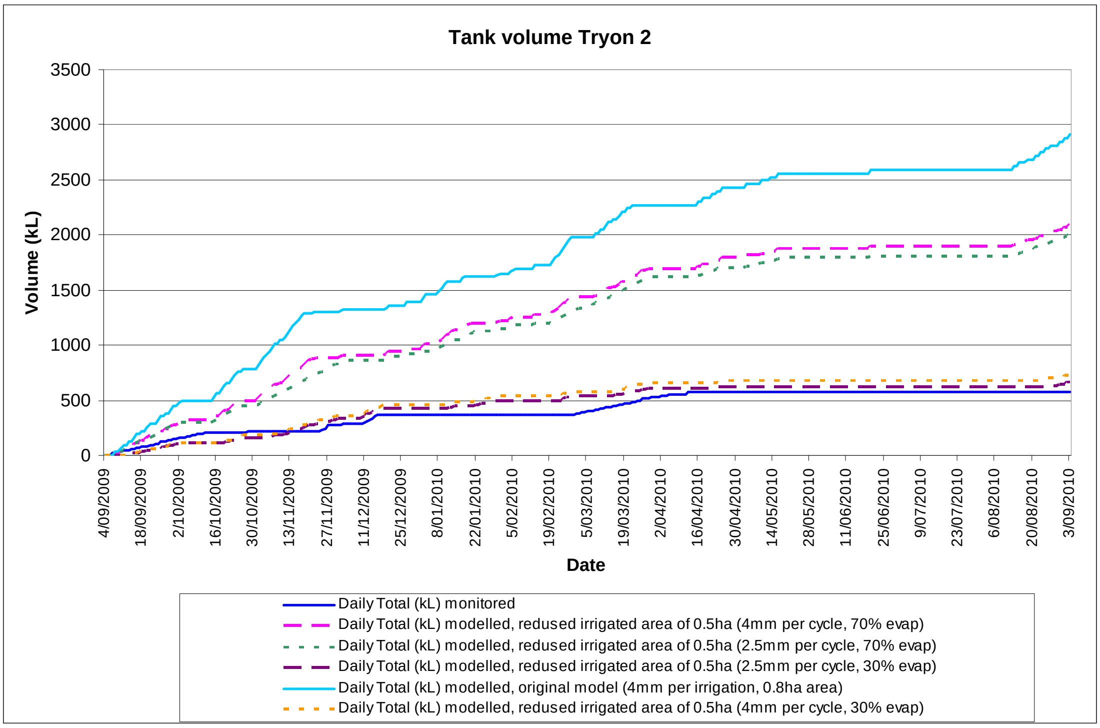


Figure 2. Tryon Oval 2 irrigation modelling (September 2009 – September 2010)

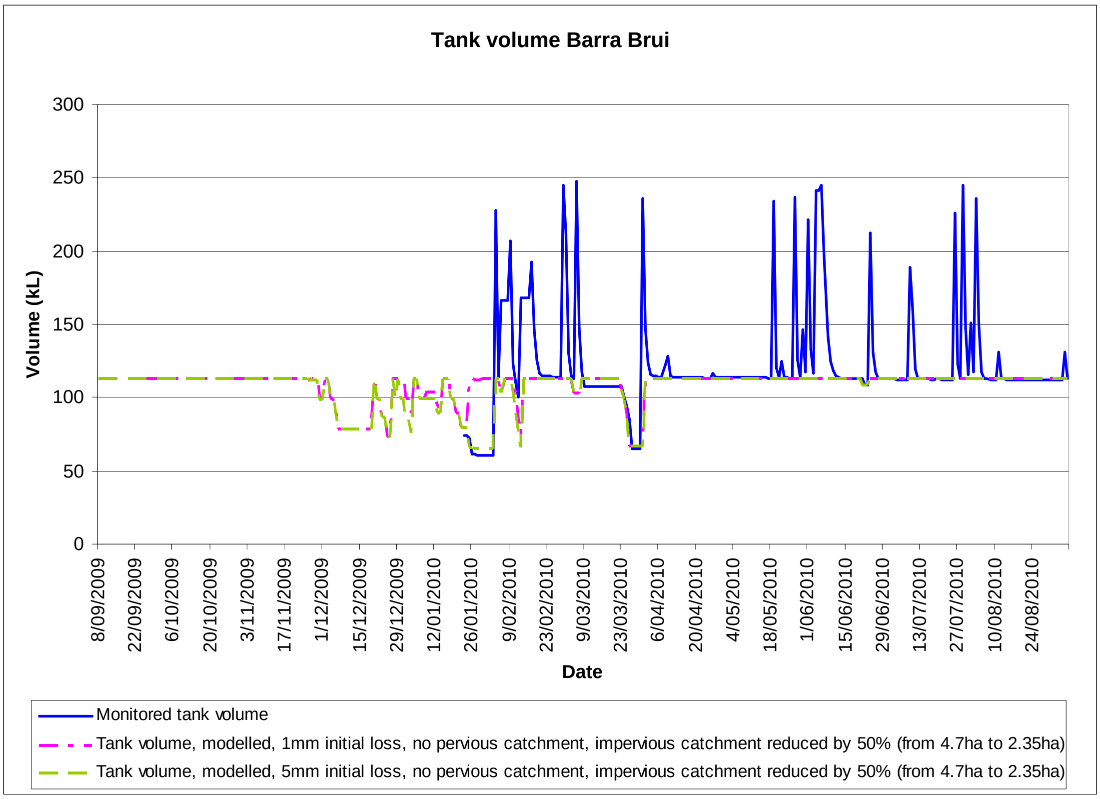
The original model (with a revised storage volume of 376kL) estimates the volume of reused stormwater to be 2,910kL, with periods of the storage being empty reducing the volume of reused water. The real volume of water used for irrigation during the modelled period was 570kL, with the storage never being critically depleted.

Runoff generation

In order to estimate the volume that enters the tank, the actual irrigation volumes from the monitoring were entered into the water balance models (rather than the modelled irrigation pattern).

Data on tank levels from Barra Brui sports field were only available from November 2009. Even though the total storage volume at Barra Brui is 250kL, water in the top half leaks out of the tank shortly after a storm event, this is shown by the spikes in the Graph in Figure 3.

A number of different scenarios were modelled for each harvesting system in order to obtain a reasonable fit between the modelling results and the monitored data. It was found that the models overestimated the volumes of water entering the tank following a rainfall event. As a result, both a reduction in the contributing impervious catchment and an increase in initial loss were modelled to achieve a better fit to the monitored data. The results are presented in Figure 3 (Barra Brui) and Figure 4 (Tryon Oval 2).



Figur*e 3. Barra Brui storage tank volumes (September 2009 – September 2010)*

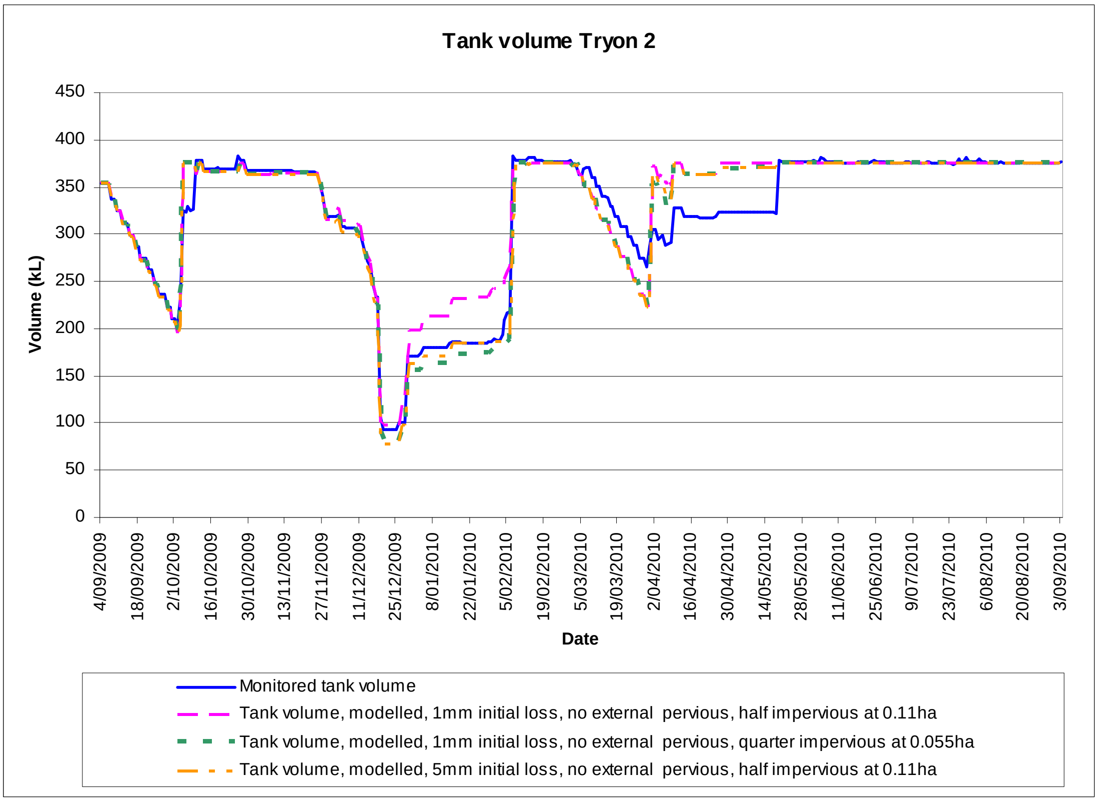


Figure 4. Tryon Oval 2 storage tank volumes (September 2009 – September 2010)

Discussion

The difference in observed volumes of water entering the storage compared to modelling results could be due to poor connectivity of the impervious catchment, or high initial losses. The initial losses may be due to cracks and uneven surfaces, or in the case of residential catchments, a high level of residential rainwater tanks. It is however unlikely that the later is the cause of the high initial losses. A combination of increased initial loss and a reduced impervious catchment returned the best fit between modelling results and observed values. This would support findings in previous studies from Ku-ring-gai (Jonasson et al 2007, Jonasson et al 2009) where a reduction in impervious catchment was required in many cases in order to obtain modelling results that compared favourably to monitored values of runoff volumes.

The reduction in the available storage volume due to overflows and sump volumes will also impact on the modelling results and should be considered during the design. If the irrigation demand was unchanged, the observed reduction in runoff volume and reduced available storage volume in the tanks would decrease the security of supply and a larger storage would be required in order to counteract this. The impact of this would be an increase in project costs.

For both Barra Brui sports field and Tryon Oval 2 the actual irrigation was however much lower than what the model estimated. This is partly due to current irrigation management, where irrigation systems are turned off during winter from May to September. It would also appear that the irrigation management strategy adopted by Council estimates an evapotranspiration of approximately 30% of pan evaporation rather than 70%. This greatly reduces the irrigation requirement.

The lack of widely adopted industry guidelines causes a problem when projects from different areas are to be compared to each other. Details of reused volumes are becoming more common as Councils report on volumes of reused water and decreased need for drinking water as part of water savings plans. However, such data is only available once a project is completed. In order to assess projects during concept development, for example during applications for external grants, it is very difficult to fairly assess two projects if the same modelling practice has not been adopted for both projects. In the case of grant applications, a model that grossly overestimates irrigation requirements will actually work in favour of the applicant, as this is likely to return a higher volume of reused water. If it is assumed that the equivalent volume of drinking water would be used for irrigation if stormwater harvesting was not adopted, such a project is likely to return a lower cost per kL of reused water, and thus a higher value for money. A project that has adopted a more conservative irrigation regime will use less water and will have a higher cost per kL. In such a case, the assumption of wasteful practice is actually rewarded.

Rainfall can be highly localised and the rainfall used for these two case studies was not obtained from the actual contributing catchments. It is acknowledged that this may have impacted the results of this case study. The fact that the result was similar to the results from previous studies and the same for both sites (i.e. the runoff volumes were less than what the models predicted), does however give some confidence in the results.

It should also be noted that the results presented in this paper should be viewed as indicative as the data sets are small and the systems themselves are different. As is the case for all modelling, small changes to any of the modelling parameters such as the irrigated area, trigger for irrigation, soil storage properties or depth of irrigation will all change the total irrigation requirement and the volumes of reused stormwater used for irrigation.

Conclusions

Both systems assessed as part of this case study did provide less volume of reused stormwater compared to what was anticipated during design. They did however provide in excess of the security of supply due to a much more conservative irrigation regime. In answering the question *"did we get what we paid for?"*, the answer will vary depending on who answers. From Council's perspective however, both systems provided volumes in excess of what is required to satisfy current irrigation regimes.

The rough verification of water balance model output for stormwater harvesting systems after implementation provided in this paper is something that is not commonly available. It highlights the need for industry guidelines in order to allow fair comparison between projects, for example as part of grant applications. By adopting sound modelling practices we will get models that do what they are supposed to do: allow optimisation of the stormwater harvesting system and thus provide best value for money.

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