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# Private assets for public benefit: the challenge of long-term management of domestic rainwater tanks

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## ABSTRACT

This study explored the relationship private landowners have with their domestic rainwater tank and how that relationship influences the reliability of privately operated rainwater tanks for long-term performance and delivery of service. It found that tank owners generally placed a high value on their tank, desired to have them fully operational and made a reasonable effort to keep them functioning. However, the frequency and extent of maintenance action and effort was variable, and in the context of a private residence, rainwater tanks were typically afforded a low relative priority for repair when compared with other residential assets. This low relative priority could be a primary driver for the reported delay between when a fault occurs with the tank and when it is repaired. This 'repair lag' means that a portion of domestic rainwater tanks are likely to be non-operational at any one time. When planning a decentralised system for the management of stormwater, redundancies should be included to cover these gaps in service delivery. It is also recommended that programmes that support private landowners to maintain their rainwater tanks are implemented to minimise repair lag.

**Key words:** community participation, decentralised systems, rainwater tanks, stormwater management

## HIGHLIGHTS

- Most rainwater tanks remain in working condition after years of operation.
- Owners were motivated to maintain their rainwater tanks, but this did not always translate into immediate action.
- The delay in maintaining tanks is possibly a result of competing priorities and limited knowledge and skill sets.
- Education and support programmes that aid owners to maintain their tanks are advocated.

## INTRODUCTION

The use of decentralised infrastructure for the management of urban environments is a widely adopted practice that often relies on the participation of privately owned properties. Long established approaches like the management of domestic sewage by septic tanks (e.g. Devitt *et al.* 2016) are now being joined by new technologies, such as household electricity generation via solar panels (e.g. Schelly 2014), grey water re-use for toilet flushing (e.g. Mankad & Tapsuwan 2011) and Stormwater Control Measures (SCMs) to manage urban stormwater (e.g. Roy *et al.* 2014). This change comes as governments acknowledge the social, economic and environmental benefits derived from using decentralised systems (Newman & Mouritz 1996) to augment the existing centralised infrastructure, as well as increased public acceptance of their use (Mankad & Tapsuwan 2011). However, the simple adoption of decentralised infrastructure does not guarantee ongoing benefits (Woelfle-Erskine 2015), with long-term maintenance of the asset being a particular challenge.

Over recent decades, domestic rainwater tanks have become an increasingly common feature of privately owned land in many countries (Mankad & Greenhill 2014; Christian Amos *et al.* 2016). This increase has been promoted by governments, who have used rainwater tanks as a decentralised response to water supply challenges, especially during times of limited water availability from the existing large-scale centralised infrastructure. Through a combination of incentive schemes and mandatory policies (Christian Amos *et al.* 2016), governments have embraced rainwater harvesting tanks on private land because of the multiple public benefits they provide. While best known for reducing the pressure on mains water supplies, rainwater tanks are now accepted as contributing to flood mitigation and the protection of waterways through the mitigation of the adverse effects of

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stormwater (Burns *et al.* 2010). While such benefits can also be a driver for private land owners (Gardiner 2009; Brown *et al.* 2016), the motivation for them to install rainwater tanks is mostly driven by the private benefits rainwater tanks provide, such as reduced cost of water supply and as an alternative water supply not subject to water restrictions, like those placed on centralised water supplies when storages are low (Moglia *et al.* 2012b; Mankad & Greenhill 2014).

While there has been significant investment by government and water management authorities to encourage the adoption of rainwater tanks on private land, limited attention has been paid to the long-term operation of these privately managed, decentralised systems (Moglia *et al.* 2013). Like most SCMs, there is often an arguably naïve expectation that once tanks are installed, they will remain functioning without further intervention (Blecken *et al.* 2017). In reporting on the success of a tank incentive scheme, government agencies report on the number of tanks installed but rarely account for how many of those remain operational in the medium-to-long term. However, authorities are increasingly concerned about the condition of tanks (Moglia *et al.* 2012a) and the level of maintenance they receive (Moglia *et al.* 2011). Indeed, Moglia *et al.* (2012a) note that there is a general lack of data on the condition of privately operated tanks. This is a significant oversight that can lead to an over-estimation of the public benefits tanks provide.

Like all infrastructure assets, rainwater tanks must be maintained to avoid failure and ensure the benefits for which they were installed are realised (Mankad *et al.* 2014; Blecken *et al.* 2017). Since responsibility for tank maintenance resides with the property owner, the value of rainwater tanks as a long-term management option (for either stormwater management or mains water substitution) can only be assessed with consideration of the management decisions made by the property owner (Gardiner 2009). To understand those decisions, it is important to comprehend the tank owner's motivation and understanding of maintenance requirements (Moglia *et al.* 2013). There is a growing body of literature focused on the maintenance of rainwater tanks on residential properties, which explores a range of issues, including the differences between mandated and voluntary tanks (e.g. Mankad & Greenhill 2014; Mankad *et al.* 2014); the psychological drivers for maintenance (Mankad *et al.* 2012; Mankad & Greenhill 2014); owner familiarity with their tank (e.g. Gardiner 2009; Moglia *et al.* 2012a); the frequency of maintenance activity (e.g. Rodrigo *et al.* 2010); the consequences for water quality (e.g. Rodrigo *et al.* 2010; Moglia *et al.* 2012a); and policy interventions to improve maintenance action (e.g. Walton & Gardner 2012; Walton *et al.* 2012).

While this study also examines a number of these issues, it differs by considering the context within which rainwater tanks reside. Residential properties have multiple assets that compete for maintenance attention, yet the existing literature typically considers tank maintenance in isolation of these. By comparing and ranking the maintenance of tanks with other commonly used and maintained private residential assets, this study sought to generate a more pragmatic understanding of rainwater tank maintenance. Most importantly, it sought a relative measure of maintenance effort across household assets, to identify where tanks 'fit' in a list of common residential assets. The aim of this study was to assess the reliability of rainwater tanks (a private asset) in making a lasting contribution to reducing demand on the water supply system and impacts of stormwater runoff on waterway health (public benefits).

## METHODS

This investigation was undertaken on rainwater tanks installed as part of the Little Stringybark Creek (LSC) Project, a catchment-scale experiment located in Mount Evelyn, a typical low-medium density residential suburb of Melbourne, Australia. Mount Evelyn has a mixed socio-economic profile, with medium total income (AU$47 k) and household size (2.9 persons) close to the national average (AU$48 k and 2.6 persons) and rates of unemployment (4.5%) lower and home ownership (87%) higher than the national average (6.9 and 65.5%, respectively). The LSC project is testing the capacity of dispersed SCMs to improve in-stream ecological condition (Walsh *et al.* 2015). Rainwater tanks were the most common SCM installed on private land, with 239 properties participating in multiple rounds of community engagement, that differed in engagement process and financial incentive offered (see Bos & Brown 2015). Tanks installed through the LSC project were typical of those installed across Australia, supplying internal, regular-demand uses, such as toilets and washing machines. Most had automatic mains backup, in case of faults or interruptions to power supply (see Walsh *et al.* 2015). Unique to the project, over half (55%) of tanks had a dedicated volume for controlled release, providing a public benefit by mimicking baseflow and ensuring detention capacity in tanks (Walsh *et al.* 2015). This controlled, 'trickle-release'

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operated passively via a modified tank outlet and typically included a small micro-filter, a component of the tank systems easily overlooked by the tank owner. As a long-term study (monitoring of the condition of LSC continues), the LSC Project provides an opportunity to examine the long-term operation and maintenance of a large number of privately owned assets offering both private and public benefit.

Between March and November 2017, a survey was distributed to the majority (232) of residential properties that had participated in the LSC Project. Excluded properties were those known to have removed their rainwater tank or who had asked to no longer receive correspondence about the project (<3% of total participants). A survey was chosen as the data collection tool based on the ease and low cost of administration; high response rates (>40%) of surveys previously used in the LSC project and the potential for respondents to remain anonymous. Anonymity was considered important for gaining a truthful account of the tank's status and use, although owners could optionally provide their street address at the end of the survey to allow for cross-referencing of tank system design and age. Surveys were distributed with a small financial incentive ($10 AU hardware voucher).

The survey comprised 23 optional questions, arranged into three parts. Part A ('You and your house') contained eight questions that sought information regarding the time of tank installation (tank 'age'); ownership of the property at the time of installation and the level of financial contribution to installation. Part B ('Status of your tank system') contained two multiple choice questions (each with an optional open-ended response) regarding completed or desired modifications to the tank system. Part C ('Operation and maintenance of your tank') contained 13, mostly multiple choice, questions concerned with: the operational status of the tank system (present and historical); the frequency of tank inspections; how often nominated components of the tank system are cleaned; and what components of the tank system have required repairs (and the associated cost). Additionally, to provide context to the survey participant's maintenance behaviour, this section questioned how quickly tank owners would respond to an operational fault in a range of common residential assets, in addition to their tank system. These assets included: lawn mower, clothes dryer, dishwasher, convection oven, home heating (the survey was conducted in winter), washing machine, microwave oven and car. They were also asked the level of financial contribution they would be willing to make to affect that repair. Part C also included a series of Likert scale questions, concerned with the owner's satisfaction with their tank and what they like/dislike about it, finishing with an open-ended question to provide any additional comments about their tank system and its operation and maintenance.

Responses to selected questions were used to classify respondents according to: (i) their level of financial contribution to the tank system (labelled 'purchaser' or 'giftee') and (ii) ownership of the property at the time of the tank's installation (labelled 'installer' or 'inheritor'). Potential differences in survey responses between these sub-groups ('purchaser/giftee' and 'installer/inheritor') were explored, with any significance identified using a $X^2$ test for independence (significance accepted at $p < 0.05$). Data on the time taken to respond to an operational fault in different residential assets were used to generate a relative rank of all assets. The use of ranks meant the analysis contextualised rainwater tank maintenance, comparing it to other private property assets rather than attempting to define an actual time to respond to a fault. Additionally, since most answers to this question were offered as ranges (e.g. 2–4 weeks), defining an absolute measure of time was nonsensical. To generate the rank, responses reporting a range were normalised using the median of the category (e.g. 2–4 weeks = 21.5 days). Comparison of relative ranking of private assets between sub-groups was compared using the Mann–Whitney $U$ test (significance accepted at $p < 0.05$).

## RESULTS

Responses were received from 156 properties, giving an overall response rate of 67%. Most respondents (83%) reported living in the house at the time of the tank's installation. Of those that purchased their house with the tank already installed ('inheritor'), most (90%, $n = 19$) recalled noticing the tank at the time of purchase, although relatively few (28%) reported that the tank's presence influenced their decision to purchase that house. The proportion of respondents that reported having contributed financially to the installation ('purchaser') of their tank system (58%, with 12% unsure) was similar to the actual rate of financial contribution for the population (55%).

Responses were received across all four incentive rounds, with a similar proportional representation for each round (ranging from 41 to 52%). All years in which tanks were installed (tank 'age') were represented in the responses, at equally proportional rates when compared with the number of installations for each year (ranging

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from 43 to 54%). The one exception is 2014, for which no responses were received but in which only one tank was installed.

### Maintenance behaviour

Most respondents (93%) reported that it was important to them that their tank system remained in 'good working order'. The motivations for this included: the protection of local creeks (94% agreement); conserving drinking water (90% agreement) and saving money on water bills (89% agreement). Fewer respondents (65%) reported that their own financial contribution towards installation was motivation to maintain the tank, with 10% reporting that financial contribution was not important (25% recorded as neutral).

Most tank owners (70%, $n = 106$) reported that they undertake regular inspections of their tank to assess its operational status. There was no significant difference between 'installer' or 'inheritor' tank owners ($X^2$ (1, $n = 158$) = 0.42, $p < 0.05$) nor between the 'purchaser' or 'giftee' tank owners ($X^2$ (1, $n = 109$) = 2.5, $p < 0.05$) in the prevalence of this maintenance routine. The frequency of these inspections varied considerably, with 'Monthly' being the most reported frequency of inspection (34%), followed closely by '3 Monthly' (26%) and '6 Monthly' (19%).

Gutters were the most maintained component, with 90% ($n = 120$) of respondents cleaning their gutters at least once per year. There was no significant difference ($X^2$ test) between 'installer' or 'inheritor' tank owners nor between the 'purchased' or 'gifted' tank owners. Tank inlet screens had a similar rate of attendance to that of gutters, with 80% ($n = 105$) reporting cleaning at least once per year, although there was greater variation in the frequency of inlet screen maintenance. Most respondents (80%, $n = 73$) reported cleaning their tank of internal sludge '0' times per year.

The survey also asked how frequently tank owners cleaned the controlled release filter. The results of this question were compared with the LSC Project's database of tank installations, noting (where possible) which respondents did or did not have a controlled release filter. Only 30% ($n = 17$) of respondents whose tank did not have a controlled release filter responded to the question accordingly with 'Not Applicable'. The remaining respondents answered on the assumption they had one, reporting they cleaned it either 0 times (52%, $n = 29$) or at least once 18% ($n = 10$) a year. Additionally, of those that did have a controlled release filter, 13% ($n = 7$) incorrectly reported that this question was 'not applicable' to them. Few respondents cleaned the controlled release filter, with only 17% ($n = 9$) reporting they cleaned it, on average, once or more per year.

When reporting on repairs made to their tank system, 39% ($n = 53$) of tank owners advised of having to make some repairs since installation. On average, repairs were required on 3 ($\pm 3.5$) separate occasions, with owners typically spending between AU$301 and $1.000 (56%, $n = 28$). Water pumps were the most common tank component requiring repair, with 85% ($n = 45$) reporting this need, compared with 30% reporting needing repairs to gutters and pipes/fittings. The length of time taken to repair these inoperative tank systems varied greatly, ranging from less than a day to a year (average 28 $\pm$ 83 days).

### Comparison with other residential assets

The 'Car' ranked first in the time taken to effect a repair on faulty residential assets (Figure 1), meaning it was the asset to which owners responded quickest when faults arose. Indeed, over 80% of respondents reported they would seek to repair their car within either '1 day' or '2–4 days', having an average relative response rate of 3.25 days. This contrasts with the tank system, which was ranked last, with 19% of respondents reporting it would take them 28 days or longer to respond. A Mann–Whitney $U$ test showed that there were no significant differences in ranking of residential assets between sub-populations for either ownership status (inheritor vs. installer; $U = 36$, $p = 0.726$) or financial contribution (purchaser vs. giftee; $U = 38$, $p = 0.857$).

The financial contribution of fault repairs for each of these household assets varied greatly (Figure 2). The 'Car' was again highest ranked, with close to 40% of respondents willing to spend over AU$1.500, while the tank system ranked fourth. The high variation in financial contribution across all assets is not unexpected, since the initial purchase cost of these assets differs significantly. As such, these results should be used with caution, as the offered contributions may reflect the initial cost of purchasing the asset. The tank system's higher rank when compared with the number of days to seek a repair (Figure 1) might be a result of being one of the more expensive residential assets, with the cost of tank installation for the LSC Project averaging AU$8.330 (range AU$625–AU$22.942), with the contribution by residential owners (where known) averaging AU$1.890 (range $0–AU$12.092).

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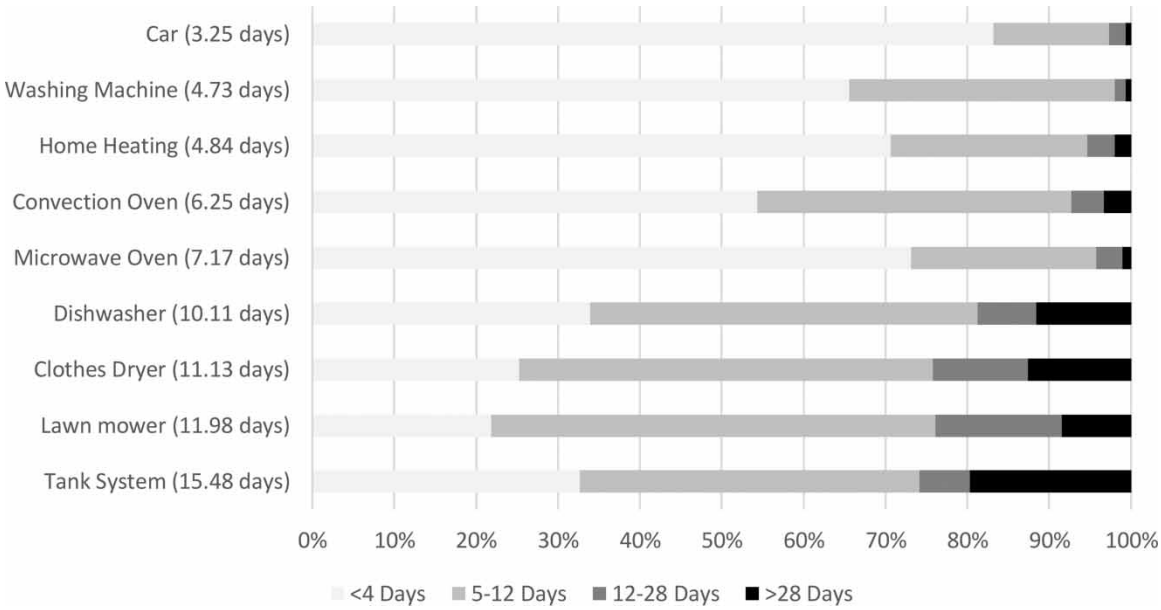



**Figure 1** | Number of days to seek a repair to common household assets, including tank systems. Assets are ranked according to the average days – this value is a relative figure, calculated from the mean value from each time length category.

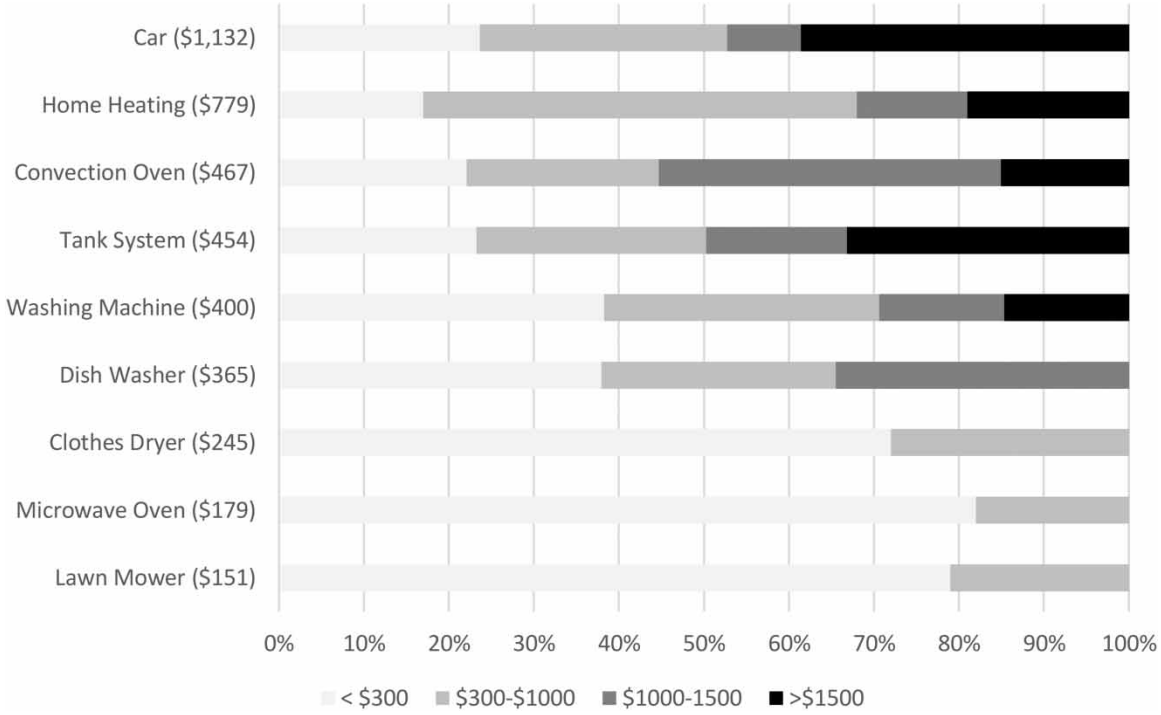



**Figure 2** | The level of maintenance spending tank owners are willing to pay to affect a repair on faulty household assets, including tank systems. Assets are ranked according to the average amount nominated by tank owners (shown in brackets), from highest (car) to lowest (lawn mower).

## Operational status

Most respondents (79%) reported that their rainwater tank system was operational at the time of the survey. This was typically reported with a high level of confidence (Table 1), with only 4% 'assuming' that the tank system was working. The age of the tank had some influence on the reported operational status, with a slight bias towards more tanks being reported as non-working for those installed in the first round of community engagement (2008–2009, 33%), compared with the second and third rounds (2010–2011, 12% and 2011–2016, 11% respectively).

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**Table 1** | Percentage responses ($n = 154$) on the operational status of the tank system (Question: Is your tank fully working today?) and the respondent's confidence in their response (if operational) and the respondent's intention to repair (if not operational)

| Current operational status | | | | |
|---|---|---|---|---|
| Operational | 79% | Confidence in assessment of status ($n = 122$) | | |
| | | Definite | Should | Assume |
| | | 71 | 25 | 4 |
| Unsure | 5% | | | |
| Non-operational | 16% | Intentions to repair ($n = 25$) | | |
| | | Yes | No | Unsure |
| | | 68 | 14 | 18 |

Of those reporting the tank as non-operational ($n = 25$), the majority (68%) reported they intended to affect repairs. The survey also identified that over a third of tanks (36%, $n = 52$) had stopped working previously, with many of these tanks being non-operational on multiple occasions (mean $3.1 \pm 3.45$) and for periods ranging from 1 day to 1 year (median = 7 days). The most common reason for the tank system being non-operational was failure of the water pump (76%, $n = 40$).

When property owners were asked if they had made any changes to their tank system since its installation, most (72%, $n = 99$) reported they had not. Those responding that changes had been made (28%, $n = 38$) were asked to describe the change. These changes were then nominally assessed as to the effect on the environmental benefits provided by the tank, being classified as either 'positive', 'negative' or 'neutral'. A modification was deemed 'positive' if it resulted in an increase in the volume of stormwater captured and/or used once harvested (e.g. installation of an additional tank). Conversely, a 'negative' effect might be, for example, the disconnection of a downpipe from the tank, leading to the reduced capture of stormwater. Only 32% ($n = 12$) were classified as being 'negative'.

### Satisfaction

Most respondents expressed satisfaction with their tank with the majority 'agreeing' (61%) or 'mostly agreeing' (17%) with the statement 'I am very happy with my rainwater tank system'. There was no significant difference between tank owners that installed their tanks and those that inherited them ($X^2$ (2, $N = 152$) = 3.06, $p < 0.05$). When asked if they would '… like to change anything (or anything else) about the tank system', the majority of respondents responded positively, with 40% ($n = 62$) reporting they were 'OK as they are' and 19% ($n = 29$) wanting to make the tank system bigger or do more. Only 3% ($n = 4$) reported wanting to have the tanks removed from their property.

## DISCUSSION

Most tank owners in this study placed a high value on their tank system and wanted to ensure its ongoing operation. Indeed, many reported having contributed significant funding to undertake repairs, a result also noted by Moglia *et al.* (2016). Despite these intentions, 16% of tanks were self-reported as being inoperative. The failure rates of rainwater tanks reported in other studies are highly variable. Moglia *et al.* (2016) reported only 5% of tanks as having faulty pumps and 9% faulty automatic pump switches, while Moglia *et al.* (2012b) reported tank failure rates (pump failure) as high as 35%. While the percentage of inoperable tanks in this study is meaningful, the impact on achieving the waterway health objectives of the LSC Project is unclear. This would depend on which individual tank systems were inoperable (the level of contribution to the objectives varies between tank systems) and whether there was a downstream treatment system that could provide some level of treatment 'insurance'. Regardless, there is cause for some concern, since urbanisation is a threshold impact on stream health (Walsh *et al.* 2005), meaning even a modest reduction in tank operation within a catchment could result in a dramatic impact on stream health. Furthermore, as indicated by the results of this study, any loss of service delivery provided by the tanks could be in effect for an extended period.

The percentage of inoperable tanks is unlikely to be static, with most owners of non-operating tanks reporting their intention to facilitate repairs. However, the length of time respondents reported having taken to complete

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repairs, combined with the lower priority afforded tanks (compared with other residential assets) to affect repairs, suggests that this will take time. The resulting 'repair lag' means that at any one time, there is likely a shifting sub-population of inoperative tanks, with tanks slowly being repaired as others develop faults.

The consequence of failing to maintain decentralised assets on private land is a reduction or loss of service delivery for both the private landowner (who gains a value from the asset) and the government or agency whose policies support decentralised infrastructure. In this scenario, the asset becomes a waste of both private and public investment and can lead to a reduced confidence in the use of decentralised infrastructure (Blecken *et al.* 2017). While governments acknowledge that private owners have a role to play in delivering public services, as expressed by the incentive schemes and policies they implement, there appears little commitment to ensuring the long-term management of these assets. Even septic tanks, perhaps the oldest of this type of dispersed infrastructure, can suffer from insufficient management policy and/or regulation (Withers *et al.* 2012).

For programmes like the LSC Project that use decentralised SCMs for waterway health objectives, there are two feasible and complimentary solutions to ensure ongoing service delivery. First is an engineered response, with the SCM network designed in such a way that it can accommodate realistic failure rates. This could be achieved by incorporating redundancies across the SCM network, so that the service delivery lost by one non-operational SCM can be provided by another SCM, located 'downstream'. The difficulty with this approach is that in established urban areas, the availability of physical space in which to build these downstream, 'insurance' SCMs is generally limited. The second solution is to ensure that the sub-population of faulty tanks remains as small as possible and that tanks are repaired promptly. This requires that appropriate policies, incentives and/or management mechanisms are established to address the challenges of maintaining rainwater tanks. Understanding the relationship private owners have with their asset and the reason they maintain them is imperative, although complex and difficult to predict (Moglia *et al.* 2013). This relationship is explored below through four factors, aspects of which were also considered by Blecken *et al.* (2017) and Moglia *et al.* (2012b): the **value** private landowners attribute to the asset; their **awareness** of its operation and their **capacity** and **willingness** (or motivation) to maintain their tank.

### Value of the tank system

In this study, owners reported a high level of satisfaction with their tanks, which was evidenced by the frequency of maintenance actions that were undertaken; the number of tank systems which had been repaired and the number of owners making positive alterations to their tank system. The perceived value of an asset is important, since given resourcing constraints, maintenance is typically prioritised towards assets of highest perceived value or where inaction will lead to significant repercussions (Chong *et al.* 2019). Indeed, Gardiner (2009) postulated that owners who did not value their tanks highly would be more likely to stop using them when faults arose. While respondents in this study reported highly valuing their tank system, the low ranking of tanks for maintenance repair time (Figure 1) suggests that tanks have a very low actual value when compared with other assets. This could be indicative of a value-action gap (Newton & Meyer 2013), which may contribute to the observed 'repair lag'. The higher rank for tank systems in maintenance funding (Figure 2) was suggested earlier as reflecting the cost of installing or purchasing an asset. However, tanks were ranked lower than home heating and convection oven (both arguably cheaper to purchase), which further suggests that tanks have a lower actual value compared with other assets.

### Awareness of operation and maintenance

Research has found that ignorance of how a tank functions and its maintenance requirements is common in tank owners and likely leads to reduced maintenance action (see Gardiner 2009; Walton & Gardner 2012; Mankad *et al.* 2014). This issue is not exclusive to rainwater tanks, with Devitt *et al.* (2016) reporting knowledge gaps as being a barrier to septic tank maintenance. Knowledge of an asset is certainly vital if the required maintenance is to be undertaken in a timely manner. However, it is important to distinguish between two levels of knowledge: that of the tank's operational status (Is it working/supplying water?) and that relating to the tank's maintenance requirements (What will stop it working and when?). Owners may not need technical knowledge of maintenance requirements if they are aware, in a timely manner, of when the tank stops operating and are willing to obtain assistance to repair it.

In this study, the confidence with which respondents reported on the operational status of their tanks and the frequency of 'routine' inspections suggests that most owners feel they have reasonable awareness of their tank's

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functionality. However, it is feasible that a tank might be considered 'operational', but because of under-maintenance it operates at a reduced capacity. For example, a partially blocked inlet screen might result in less water entering the tank and being available for use. In such situations, owners less familiar with their tank system could mistakenly believe that their tank is fully operational when it is not (Gardner & Vieritz 2010). Having only a rudimentary perception of the tank's operation (it is/isn't supplying water) might, therefore, be insufficient to ensure the tank is providing all the services it is designed to deliver. This is compounded by the lack of visual cues to indicate maintenance is required, a barrier to maintenance also identified for septic tank systems (Devitt *et al.* 2016). This is particularly pertinent given the inbuilt redundancy of most tank systems, which automatically revert to mains water when the tank is empty, or the pump is non-operational. This is a notable contrast to other private assets, such as cars or home heating, where faults (and the resulting consequences) are typically easier and more immediate to recognise.

Having a greater familiarity with the tank system, what maintenance will be required and when, could therefore be important to ensure the sustained operation of a tank system. Indeed, in this study, despite tank owners reporting frequent inspections and cleaning, there was evidence to suggest a level of ignorance of the tank system's operation. This is exemplified by the misreporting of the controlled release filters. It is possible then that tank owners are aware of the general functionality of their tank but fail to understand the technical elements, as demonstrated by this comment:

'*We just feel that since it was installed we have never known if its working correctly and there is no easy way of checking. We do clean the gutters but were never shown other ways in which to care for our tank.*'

Maintenance actions that benefit the rainwater tank system might be more likely when they form part of a 'typical' maintenance programme for residential properties. Roof gutters are a good example of this, being the most frequently maintained component for the tank system in both this and other studies (Gardiner 2009; Walton & Gardner 2012).

### Capacity to maintain

Owners can only be relied upon to contribute to the maintenance of their tank system if they have capacity to do so (Moglia *et al.* 2015). Unfortunately, several studies have found that owners generally lack the skills and capacity for tank maintenance (Gardiner 2009; Sofoulis 2015). The immediate result of this is the incapacity of owners to perform maintenance tasks, even if motivated to so do. An additional consequence is that it can reduce the confidence of owners regarding tank management, making maintenance less likely (Gardiner 2009; Mankad *et al.* 2014). This study did not sufficiently explore the level of awareness of and capacity to respond to tank maintenance requirements, focusing more on the effort. However, this was clearly an issue for tank owners, with numerous comments provided regarding uncertainty of maintenance needs, such as:

'*I am, however, a bit in the dark when it comes to maintenance as we have no manuals or guides available.*'

and

'*… it would have been valuable information to explain about the fittings and maintenance as I didn't know about any of those requirements.*'

Such comments were often expressed by those that had purchased the house with the tank already installed:

'*When I moved in I didn't get an* (sic) *manuals on the operation of the tank system. I would like someone to explain the system to me and to show how to maintain it.*'

and

'*Be valuable to have information on installation of tanks installed by previous owners of property.*'

The capacity to maintain an asset not only relates to having the necessary knowledge and technical skills to implement self-maintenance, but also the financial capacity to undertake repairs. This could include either the

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capacity to purchase required components or obtain professional support. Blecken *et al.* (2017) found that financial costs were a barrier to maintenance being performed properly. Unfortunately, the socio-economic factors influencing maintenance have received limited attention (Willetts *et al.* 2007). This study also failed to explore this issue in depth, although the low relative rank of tanks for maintenance spending (which was disproportionate to the installation cost) suggests that socio-economic issues could influence maintenance practice.

### Motivation to maintain

What motivates owners to implement a tank maintenance regime has recently become a well-studied field. Research has identified several drivers, including feelings of capability or competence; moral obligation, greater perceptions of autonomy; the type of tank installed; cost efficiency; favourable attitude; personal experience and self-identify (Walton & Gardner 2012; Mankad *et al.* 2015).

Survey respondents in this study reported high satisfaction with their tank and a commitment to keeping it operational, the drivers for which they reported as being stream protection, money saving and conserving drinking water. This could mean that owners would have a high level of motivation to maintain their tank system, as reported in similar studies (e.g. Gardiner 2009; Mankad *et al.* 2012; Walton & Gardner 2012). Indeed, comments received via the survey indicate a propensity to maintain tanks:

'*I think it would be good to have a check list as I am unsure what maintenance is required myself. I could be taught to attend myself*.'

and

'*Would be happy to do maintenance to water tank but unsure how*.'

However, this apparent high motivation contrasts to the low rank (longest number of days) tanks were afforded for the time owners would take to affect a repair, again suggesting a gap between the value and action. Such ambiguity might be expected, since private tank maintenance is recognised as complex and dynamic (Moglia *et al.* 2012a), with different types of owners shown to display different levels of motivation towards tank maintenance (e.g. Walton & Gardner 2012; Mankad *et al.* 2015). Moreover, Devitt *et al.* (2016) recorded a similar ambiguity for septic systems, noting that while owners acknowledged the risks of failure, this did not translate into a rigorous management regime.

A contributing factor for the contrast between reported motivation and expected action is that those assets ranked highest (shortest number of days to repair), like cars and washing machines, could be considered by owners as assets 'vital' to their life, without readily available alternatives. That is, their failure can result in significant disruption to the homeowner, because there is no easily sourced alternative or inbuilt fail-safe. This contrasts with rainwater tanks in urban settings, which are almost always connected as a supplementary water supply, with mains potable water always available. This means there is no immediate consequence for the tank's failure. Moglia *et al.* (2015) suggest that this 'low stakes' setting could contribute to low motivation to maintain tanks in urban catchments. Similar conclusions have also been drawn for publicly managed SCMs, with responsible authorities having a reactive or 'incident' approach to maintenance, with priority given to assets most likely to be a nuisance risk, such as causing local flooding (e.g. McDonald 2018).

### Solutions to improve long-term maintenance

As found in this study, research has shown that many owners appear willing to manage their asset (Mankad *et al.* 2012, 2015; Walton *et al.* 2012). However, relying solely on the good intentions and the existing capacity of homeowners is risky, given issues such as repair lag and the potential complacency, ignorance and inexperience of asset owners. Moglia *et al.* (2011) suggest that while many professionals believe that maintenance should remain the responsibility of the asset's owner, there is growing evidence that suggests this is suboptimal.

It is becoming clear that some type of programme or policy is required to ensure long-term maintenance (e.g. Gardner & Vieritz 2010; Walton *et al.* 2012). What is less clear, however, is the form that such a programme should take, since it must strike a balance between efficacy and the receptivity by the asset's owner. Additionally, any programme must also balance the owner's responsibility with the reward for maintenance (Hills & Worthing

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2006) and consider that acceptance or success of any programme could vary between different communities (Moglia *et al.* 2012a; Walton *et al.* 2012) and be influenced by who bears the financial cost.

Greater regulation and compliance are an often-considered approach in the literature. Butler & Payne (1995) suggest that such programmes have worked for septic tanks in some European countries. However, Moglia *et al.* (2011) warn that the cost of the required inspections would need to be considered against the benefits. Additionally, both Walton *et al.* (2012) and Walton & Gardner (2012) found that regulatory and monitoring programmes were ill-favoured by both policy-makers and community members, while Moglia *et al.* (2015) suggest that such an approach could easily be seen as 'overstepping the mark'. Similarly, programmes that involve authorities (such as water utilities) being responsible for maintenance have also been poorly received (Mankad *et al.* 2012, 2015), especially if coupled with an annual service fee (Moglia *et al.* 2011). Even programmes that involve outsourcing of tank maintenance have been found to be ill-favoured (Mankad *et al.* 2015). However, such approaches are not without support from some sectors of the community, as evidenced by comments provided through this study's survey:

> '*A regular maintenance management* (sic) *would be most beneficial. Being a widow of 77 years I have no understanding of the system at all. … As long as maintenance fees are reasonable – as I am on a pension – I would appreciate not having to worry about it working or not.*'

Indeed, participants in this study were specifically asked if they would be happy to pay a small fee to have their tanks inspected annually, to which half (52%) responded that they would.

The more widely accepted approach to encourage maintenance and the one that perhaps offers the best hope are programmes that offer greater collaboration between authorities and the asset owner (Hills & Worthing 2006; Moglia *et al.* 2011). This would likely be centred around a self-managed programme, with authorities providing support tailored to the needs of different segments of the community (Mankad *et al.* 2012, 2015; Walton *et al.* 2012). An essential pillar of that support would be increased education on maintenance to build awareness, confidence and the capacity of private asset owners. Improved education of asset owners is commonly cited as being vital to good maintenance practice (Butler & Payne 1995; Hills & Worthing 2006; Moglia *et al.* 2011; Walton *et al.* 2012; Mankad *et al.* 2014, 2015; Sofoulis 2015), a need reflected by comments received through the survey:

> '*Information on maintenance e.g. pump and local people that are qualified to fix problems as well as clean tank and filters if required. Especially older people and those unable to do it themselves.*'

and

> *I would like to have it explained on how the system works …*

Similarly, the use of incentives (e.g. a property rates rebate) is also commonly suggested as being viable and well received by the community (Hills & Worthing 2006; Walton & Gardner 2012). Finally, the use of new 'real-time monitoring and control' technologies is also touted as a potential solution to private asset maintenance, especially where community engagement has been unsuccessful (Gardner & Vieritz 2010). Such technology might enhance the owner's awareness about when and what maintenance is required (especially if linked to a smart phone 'App'), or facilitate remote monitoring, that will allow for a centralised support programme (Xu *et al.* 2018). Either way, it is important that the technology adopted is simple and low cost, so that it does not, in itself, become a maintenance challenge (Blecken *et al.* 2017).

## CONCLUSION

This study found that a small, but non-negligible portion of rainwater tanks is unlikely to be operating at any one time, in part due to repair lag. As such, authorities implementing decentralised infrastructure programmes for stormwater management should consider incorporating some system redundancy to ensure the desired level of service delivery is maintained long term. This could be achieved through the installation of either additional assets (exceeding minimum requirements) or the inclusion of downstream 'insurance' treatments. Moreover, this study supports the development of dedicated tank maintenance programmes to minimise the number of

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non-operational tanks long term. These programmes will need to consider the complexity of rainwater tank maintenance, especially how tank owners vary in their capacity and motivation to manage this asset. As such, a programme that is flexible and adaptable to individual needs is more likely to be successful. Further research is required on this matter, to better understand what support programmes asset owners require and would be willing to accept, as well as how such programmes would be funded.

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## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

## REFERENCES

Blecken, G.-T., Hunt III., W. F., Al-Rubaei, A. M., Viklander, M. & Lord, W. G. 2017 Stormwater control measure (SCM) maintenance considerations to ensure designed functionality. *Urban Water Journal* **14** (3), 278–290.

Bos, D. G. & Brown, H. L. 2015 Overcoming barriers to community participation in a catchment-scale experiment: building trust and changing behavior. *Freshwater Science* **34** (3), 1169–1175.

Brown, H. L., Bos, D. G., Walsh, C. J., Fletcher, T. D. & RossRakesh, S. 2016 More than money: how multiple factors influence householder participation in at-source stormwater management. *Journal of Environmental Planning Management* **59** (1), 79–97.

Burns, M. J., Fletcher, T. D., Hatt, B., Ladson, A. R. & Walsh, C. J. 2010 Can allotment-scale rainwater harvesting manage urban flood risk and protect stream health? *J NOVATECH*. Available from: https://urbanstreams.net/lsc/Docs/Presentations/Burnsetal2010.pdf.

Butler, D. & Payne, J. J. B. 1995 Septic tanks: problems and practice. *Building Environment* **30** (3), 419–425.

Chong, A. K. W., Mohammed, A. H., Abdullah, M. N. & Rahman, M. S. A. 2019 Maintenance prioritization – a review on factors and methods. *Journal of Facilities Management* **17** (1), 18–39.

Christian Amos, C., Rahman, A. & Mwangi Gathenya, J. 2016 Economic analysis and feasibility of rainwater harvesting systems in urban and peri-urban environments: a review of the global situation with a special focus on Australia and Kenya. *Water* **8** (4), 149.

Devitt, C., O'Neill, E. & Waldron, R. 2016 Drivers and barriers among householders to managing domestic wastewater treatment systems in the Republic of Ireland; implications for risk prevention behaviour. *Journal of Hydrology* **535**, 534–546.

Gardiner, A. 2009 Domestic rainwater tanks: usage and maintenance patterns in South East Queensland. *Water: Journal of the Australian Water Association* **36** (1), 151.

Gardner, T. & Vieritz, A. 2010 The role of rainwater tanks in Australia in the twenty first century. *Architectural Science Review* **53** (1), 107–125.

Hills, S. & Worthing, D. 2006 Private home, public cultural asset: the maintenance behaviour of listed building owner-occupiers. *Journal of Housing and the Built Environment* **21** (2), 203–213.

Mankad, A. & Greenhill, M. 2014 Motivational indictors predicting the engagement, frequency and adequacy of rainwater tank maintenance. *Water Resources Research* **50** (1), 29–38.

Mankad, A. & Tapsuwan, S. 2011 Review of socio-economic drivers of community acceptance and adoption of decentralised water systems. *Journal of Environmental Management* **92** (3), 380–391.

Mankad, A., Chong, M. N., Umapathi, S. & Sharma, A. 2012 *The Role of Physical and Psychological Factors in Understanding Rainwater Tank Maintenance*. Urban Water Security Research Alliance Technical Report No. 64.

Mankad, A., Chong, M. N., Umapathi, S. & Sharma, A. 2014 Basic psychological needs influencing the regularity of domestic rainwater tank maintenance. *Water Resources Management* **28** (12), 4059–4073.

Mankad, A., Fielding, K. & Tapsuwan, S. 2015 Public perceptions, motivational drivers, and maintenance behaviour for urban rainwater tanks. *Rainwater Tank Systems for Urban Water Supply*. International Water Association, London, pp. 181–203.

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McDonald, R. K. 2018 *Sustainable Urban Drainage Systems (SUDS) in Scotland: Assessment of Monitoring and Maintenance Within Local Authorities and Scottish Water*. Available from: https://www.climatexchange.org.uk/media/3239/sustainable_urban_drainage_systems_in_scotland.pdf (accessed January 2021).

Moglia, M., Tjandraatmadja, G. & Sharma, A. 2011 How long will a rainwater tank last? Do you know. In *UWSRA 3rd Science Forum: Science Forum and Stakeholder Engagement: Building Linkages, Collaboration and Science Quality*, Brisbane, Australia.

Moglia, M., Sharma, A. K., Tjandraatmadja, G., Walton, A. & Gardner, J. 2012a Strategies for managing the condition of rainwater tanks in South East Queensland. In: *Science Forum and Stakeholder Engagement: Building Linkages, Collaboration and Science Quality* (D. K. Begbie, S. J. Kenway, S. M. Biermann & S. L. Wakem, eds). Urban Water Security Research Alliance, Brisbane.

Moglia, M., Tjandraatmadja, G., Walton, A., Sharma, A., Umapathi, S. & Gardner, J. 2012b *Proposed Strategy Portfolio for the Management of Rainwater Tanks: The South East Queensland Case*. Technical Report No. 75. Urban Water Security Research Alliance.

Moglia, M., Tjandraatmadja, G. & Sharma, A. K. 2013 Exploring the need for rainwater tank maintenance: survey, review and simulations. *Water Science and Technology: Water Supply* **13** (2), 191–201.

Moglia, M., Walton, A., Gardner, J. & Tjandraatmadja, G. 2015 Management and operational needs for urban rainwater tanks. In: *Rainwater Tank Systems for Urban Water Supply: Design, Yield, Energy, Health Risks, Economics and Social Perceptions* (A. K. Sharma, D. Begbie & T. Gardner, eds). International Water Association, London, pp. 151–179.

Moglia, M., Gan, K., Delbridge, N., Sharma, A. K. & Tjandraatmadja, G. 2016 Investigation of pump and pump switch failures in rainwater harvesting systems. *Journal of Hydrology* **538**, 208–215.

Newman, P. & Mouritz, M. 1996 Principles and planning opportunities for community scale systems of water and waste management. *Desalination* **106** (1–3), 339–354.

Newton, P. & Meyer, D. 2013 Exploring the attitudes-action gap in household resource consumption: does 'environmental lifestyle' segmentation align with consumer behaviour? *Sustainability* **5** (3), 1211–1233.

Rodrigo, S., Sinclair, M. & Leder, K. 2010 A survey of the characteristics and maintenance of rainwater tanks in urban areas of South Australia. *Water Science and Technology* **61** (6), 1569–1577.

Roy, A. H., Rhea, L. K., Mayer, A. L., Shuster, W. D., Beaulieu, J. J., Hopton, M. E., Morrison, M. A. & Amand, A. S. 2014 How much is enough? Minimal responses of water quality and stream biota to partial retrofit stormwater management in a suburban neighborhood. *PLoS One* **9** (1), e85011.

Schelly, C. 2014 Residential solar electricity adoption: what motivates, and what matters? A case study of early adopters. *Energy Research & Social Science* **2**, 183–191.

Sofoulis, Z. 2015 The trouble with tanks: unsettling dominant Australian urban water management paradigms. *Local Environment* **20** (5), 529–547.

Walton, A. & Gardner, J. 2012 *Rainwater Tank Maintenance: Community Perceptions of Policy Options*. Technical Report No. 71. Urban Water Security Research Alliance.

Walton, A., Gardner, J., Sharma, A., Moglia, M. & Tjandraatmadja, G. 2012 *Exploring Interventions to Encourage Rainwater Tank Maintenance*. Technical Report No. 59. Urban Water Security Research Alliance.

Walsh, C. J., Fletcher, T. D. & Ladson, A. R. 2005 Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. *Journal of the North American Benthological Society* **24** (3), 690–705.

Walsh, C. J., Fletcher, T. D., Bos, D. G. & Imberger, S. J. 2015 Restoring a stream through retention of urban stormwater runoff: a catchment-scale experiment in a social–ecological system. *Freshwater Science* **34** (3), 1161–1168.

Willetts, J., Fane, S. & Mitchell, C. 2007 Making decentralised systems viable: a guide to managing decentralised assets and risks. *Water Science and Technology* **56** (5), 165–173.

Withers, P. J. A., May, L., Jarvie, H. P., Jordan, P., Doody, D., Foy, R. H., Bechmann, M., Cooksley, S., Dils, R. & Deal, N. 2012 Nutrient emissions to water from septic tank systems in rural catchments: uncertainties and implications for policy. *Environmental Science & Policy* **24**, 71–82.

Woelfle-Erskine, C. 2015 Rain tanks, springs, and broken pipes as emerging water commons along Salmon Creek, CA, USA. *ACME: An International Journal for Critical Geographies* **14** (3), 735–750.

Xu, W. D., Fletcher, T. D., Duncan, H. P., Bergmann, D. J., Breman, J. & Burns, M. J. 2018 Improving the multi-objective performance of rainwater harvesting systems using real-time control technology. *Water* **10** (2), 147.

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