Proposed Strategy Portfolio for the Management of Rainwater Tanks: the South East Queensland Case

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

C. Davis

Chris Davis
Chair, Urban Water Security Research Alliance

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EXECUTIVE SUMMARY

It is estimated that in 2010 there were more than 300,000 rainwater tank systems across South East Queensland (SEQ). If one assumes an average investment cost of over $3,000 per tank, including the cost of the tank and installation, this represents an investment by the community of around $1 billion. To put this in perspective, this is a similar investment cost to the Gold Coast Desalination Plant, $1.126 billion, delivering a capacity of 125 ML/day. Rainwater tanks are now an important part of infrastructure in the SEQ water supply, with internally plumbed rainwater tanks clearly reducing the direct reliance on mains water supplies (Chong *et al.*, 2011a).

Rainwater tanks are privately owned but they also provide a public good, allowing major investments to be deferred and thus allowing the price of water to be minimised. This defines a management dilemma, given the discord between individuals' responsibility and the accrued benefit for the community as a whole.

As with any infrastructure, operation and maintenance are the critical elements of keeping rainwater tanks operable. Unfortunately, there is not adequate data on whether the installed infrastructure is in a condition to provide the anticipated benefits over the long term. Furthermore, there are concerns about the public health risks associated with rainwater tank systems in poor condition. Therefore, there are good reasons for water planners to be concerned about the maintenance of the tank systems. There is a need to rely on householders' goodwill in inspecting and maintaining tanks. This is in contrast to the rural situation where rainwater tank systems often provide the only potable water supply for householders, so there is a driver for a higher level of maintenance by the householder.

This paper integrates the findings from a series of four interconnected studies that aimed to address the long term management of rain water tanks. The data from each study was used in a Bayesian Network analysis to explore the efficiency of management strategies.

The results of the first part of the study indicated that there is a real concern about rainwater tanks and their operating and maintenance (O&M) amongst a large number of stakeholders, but the empirical data to support this was minimal. The perception of frequency of rainwater tanks failure is high and inspections and regular maintenance are seen as critical to ensure that tanks are in good condition and providing adequate benefit to the community. However, there was a high level of variability in the perception of rainwater tank O&M status and perceived householder practices among various stakeholder groups. More reliable data was thought to be required in order to undertake a cost-benefit analysis of management strategies (Moglia *et al.*, 2011). It is also clear that the majority of those surveyed and interviewed believe that the main responsibility for operation and maintenance of tanks ought to be retained by householders. Householders then need the incentive and to be empowered to manage this private infrastructure which has public benefits. Whilst the first part of the study provided some insights into the current legislative, technical and institutional context of rainwater tanks in SEQ, it also described professional judgments and experience elicited on the management concerns of rainwater tanks.

The second part of the study used a workshop approach, involving industry and government stakeholders and identified possible options for managing ongoing tank maintenance (Walton *et al.*, 2012). The options ranged from regulatory approaches, such as certifying tank ownership and inspecting tank maintenance, through to enabling approaches, such as creating increased awareness through promotional campaigns and educational activities. The workshop participants preferred enabling approaches as the mechanisms to encourage homeowners to voluntarily take on responsibility of maintaining their tanks. Improvements to tank design and installation procedures were also identified as effective options that could reduce the burden of long term tank maintenance on tank owners.

The third part of the study used focus groups to explore community attitudes towards tank maintenance and to examine community acceptance of possible management approaches for ongoing tank maintenance (Walton and Gardner, 2012). Results demonstrated a general lack of awareness by the community for the need to maintain a tank and strong preferences for using enabling measures, such as incentives or education, to encourage and ensure tanks were maintained. Community feedback indicated that regulatory approaches to management would be viewed as unfair and potentially ineffective, with such approaches considered to reduce the benefits to tank owners of having a tank.

This final report covers the last part of a study that has explored the possible ways that rainwater tanks can be managed in the SEQ context. It follows on from the previous studies by describing how the various activities feed into the definition and evaluation of a proposed management strategy. This is done by means of modelling and using data from the entire study.

The key output of the study is a strategy portfolio for managing rainwater tanks in SEQ, proposed as a possible way forward for stakeholders. The strategy portfolio has three phases. The first phase involves reviewing the need for regulatory changes as well as centralising existing data on rainwater tank systems, and developing methods for managing this data. The second phase involves random rainwater tank inspection programs and making the required changes to standards and guidelines, undertaking training of plumbers, updating of the post-installation certification processes, and analysis of the efficacy of all these actions as measured by the statistical improvement of the condition of tanks. The third phase involves review of prior actions, evaluation of the associated health risks, and to revise actions or decisions as appropriate. Throughout the three phases, targeted communication and support for householders is recommended.

1. INTRODUCTION

Rainwater harvesting and collection in tanks as a supplement to water provisions is adopted widely in many cities around the world. Uptake of this practice is driven by the need to provide water when other sources are inadequate for ensuring safe and sustainable supply (Sharma *et al.*, 2008; Zhang *et al.*, 2010). For example, in Australian cities, household rainwater tanks have been promoted by various levels of government by means of legislation, rebate schemes and subsidies as a way to reduce the severity of water restrictions, and to improve the supply-demand balance. As a consequence, the uptake of rainwater tanks for suitable dwellings[1] is above 40% in some major capital cities such as Brisbane and Adelaide. Rainwater tanks provide an increasingly important contribution to urban water supplies and it can therefore be argued that it is important to protect the government's and community's investment in such infrastructure.

In South East Queensland (SEQ), rainwater tank uptake has increased markedly. From 2007 to 2009, the uptake of rainwater tanks in the Queensland increased by 15.9%, with rainwater tanks installed in 38% of households by 2009 (Australian Bureau of Statistics, 2007, 2009). Brisbane experienced the largest uptake; with rainwater tanks in 43% of suitable dwellings (Australian Bureau of Statistics, 2010). Rebate programs contributed to over 230,000 domestic rainwater tanks installed between 2006 and 2008 (Walton and Holmes, 2011), Across Queensland, all new, single dwellings built after 1 January 2007 were required to have rainwater tanks and/or other non-mains water sources installed (such as greywater treatment plants, communal rainwater tanks, dual reticulation or treated stormwater) in order to meet specified mains water savings targets (Queensland Government, 2008). Between 2007 and 2010, these changes in the local development code, referred to as the Queensland Development Code MP4.2 (Queensland Government, 2008), resulted in an additional 30,000 tanks installed in new homes (Gardiner, 2010). Rainwater tank uptake is highest in new dwellings, with 57% of new houses less than one year old being connected to a rainwater tank (Australian Bureau of Statistics, 2010).

The costs of installing and operating rainwater tanks are, in many circumstances, competitive compared to alternative water sources, such as additional dams or desalination plants, but this competitiveness depends on the exact costs of maintenance (Tam *et al.*, 2010). From a water management and planning perspective, rainwater tanks provide some public good benefits, in the form of water savings and can assure an independent supply during water restrictions, plus provide reductions in peak stormwater runoff. Chong *et al.* (2011a) clearly demonstrated that dwellings with internally plumbed rainwater tanks can reduce the direct reliance on mains water supplies, with an average mains water saving of 58.2 kL/hh/yr in 2010, approximately 33% of the water used in residential properties in 2010 in SEQ.

This considerable investment in private infrastructure is considered by water planners in their projections, thereby being able to delay major investments in public infrastructure such as desalination facilities or new dams. It is therefore of critical public interest to protect this investment. In Australia however, some water planners and water utilities are becoming increasingly concerned about the condition of the stock of rainwater tanks in private backyards. There is currently very little knowledge of the current state of the rainwater tank asset stock and there are limited data to gauge whether there is a real need for concern.

This report integrates the findings of four interconnected studies into a Bayesian Network analysis, and presents an overall strategy for managing rain water tanks. The report proceeds with an initial summary of the four interconnected studies: 1) initial investigations; 2) stakeholder workshop; 3) community focus groups; and 4) follow up interviews and surveys. Detailed reports of the four studies that underpin this research can be found as follows: Moglia *et al.*, 2011a; Walton *et al.*, 2012; Walton and Gardner, 2012. The Bayesian Network modelling is then presented and simulation results discussed. The report concludes with discussion of a proposed three-part strategy recommended for the ongoing management of rain water tanks, focusing on tank design, tank installation and tank maintenance.

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[1] In this context, the Australian Bureau of Statistics define a "suitable dwelling" as a separate house, semi-detached, row/terrace house, townhouse etc.

2. STUDY PRINCIPLES

A key charter in this study is to develop an action strategy for the management of rainwater tanks in a way that involves stakeholders (defined as per Nandalal and Simonovic, 2003) in an active manner. Therefore, key principles of the study are (HarmoniCOP, 2005):

- Need to identify and involve all stakeholders in the process.
- Allow stakeholders to have some input into the identification of strategy alternatives.
- Strive for communication and engagement with all stakeholders.
- Strive to increase the awareness of the interest and preferences of all stakeholders.
- Contentious topics involve issues that can create real strife or moral outrage amongst stakeholders, and these therefore need to be identified.
- Handle and attempt to resolve conflict in a way that aims to find compromise or consensus solutions.
- Being clear about the role of researchers as providing information and to facilitate discussion.
- Ensuring research process provides multiple alternatives from which decision makers can choose.

These participatory considerations have (Jones *et al.* 1999):

- Normative functions by increasing the legitimacy of the process of knowledge generation.
- Substantive functions by allowing greater integration of more sources of knowledge and information, hence improving the capacity for problem solving.
- Instrumental functions by trying to help build collaborative relationships to assist with implementation of strategies and for reducing conflict.

3. PRIOR RESEARCH ACTIVITIES

This study builds on the prior explorations providing an understanding and describing the context of rainwater tank management in SEQ (Moglia *et al.*, 2011a), exploring the available data and professional judgments on rainwater tank conditions (Moglia *et al.*, 2012) and the carrying out of focus groups and workshops investigate community attitudes (Walton *et al.*, 2012). After this, the authors have undertaken interviews with selected experts in urban water management to quantify a Bayesian Network (BN) model, which empirically describes the design of a management strategy for rainwater tanks. Finally, a strategy for rainwater tank management is described, with some rough estimates of costs and discussion concerning implementation.

As shown in Figure 1, this study has progressed from phase 1, by first undertaking a stakeholder workshop to identify a number of management options. These management options have been deliberated in community focus groups in order to understand community preferences. To the extent possible, the information from follow-up interviews, surveys and miscellaneous prior knowledge has been incorporated into the BN model to understand what types of management strategies may achieve an outcome acceptable to key stakeholders. This is the starting point of identifying a staged action strategy. There has been some very approximate cost assessment and, using BN models, some approximate impact assessment. Further discussion needs to occur to understand the legislative and practical feasibility of the identified rainwater tank management strategy, in order to move towards implementation.

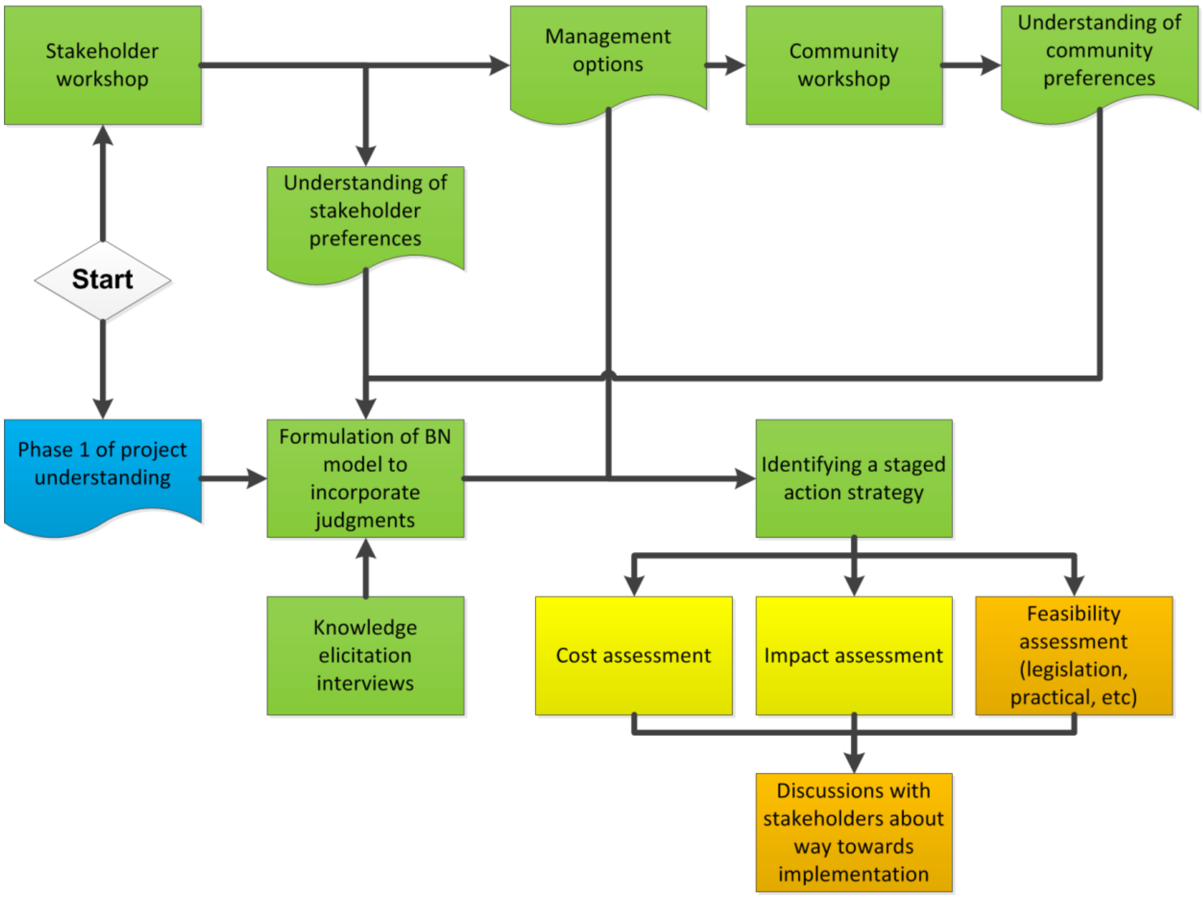


Figure 1: Research activities in sequence.

Note: Figure 1 shows the research activities in year 2 of the study, starting as indicated with a stakeholder workshop and taking into consideration the understanding developed in year 1 (blue box). Green boxes are those tasks that are considered completed; yellow boxes are completed for the purposes of this study but can be improved to be fully adequate; and orange boxes are aspirational goals based on what is required to move towards implementation of strategies.

3.1. Initial Investigations

The first part of the study involved a number of questions (Moglia *et al.*, 2011a):

- What is the current institutional context of rainwater tanks in SEQ?
- Is there a need for a new governance mechanism for rainwater tanks in SEQ?
- What is known and not known about the condition of rainwater tanks?
- What are the possible mechanisms for governance of rainwater tanks in SEQ?

These questions were explored with the following activities (Moglia *et al.*, 2011a):

- Review of the literature on rainwater management (state of knowledge and legislative framework);
- Interviews with key stakeholders' representatives (government, private practitioners, researchers) on their views on rainwater tank management and associated risks;
- Web-based survey of over 250 professionals associated with rainwater tanks on their perceptions on rainwater tank issues, risks, management and governance needs; and
- Mont Carlo simulation of failure rates using the perceived risks and management practices to evaluate the impact of operation and maintenance (O&M) practices.

Based on these activities, it was found that there is a real concern about rainwater tanks and their O&M amongst a fairly large group of people. If the perceptions of how often rainwater tanks fail are anything to go by, then inspections and regular maintenance is critical to ensure that a decent proportion of tanks are in good condition and providing adequate benefit to the community. This was further explored using Mont Carlo simulation by which the benefit of regular O&M was evaluated. However, there was high variance in the perception of rainwater tank O&M status and householder practices among various stakeholder groups. More reliable data was considered to be required in order to undertake a cost-benefit analysis of inspections.

It was also clear that very few of those interviewed or who were participants in workshops would like anyone other than householders to have the main responsibility for operation and maintenance of tanks. So, if the status quo is unsustainable but householders remain responsible, any governance arrangements would need to include a collaborative approach with householders. Householders need to have adequate incentive and be empowered to manage this private infrastructure which has public benefits. Provision of information to householders was seen as critical.

The selected insights from the first phase of this research (as described in Moglia *et al.*, 2011; Moglia *et al.*, 2011a, 2012; Walton *et al.*, 2012; Walton and Gardner, 2012; Biermann *et al.*, 2012) are that:

- Management of rainwater tanks is a highly contentious issue because the tanks are private property that contributes to achieving public good outcomes and government interference is often viewed in a negative light.
- Perceptions regarding the overall condition of rainwater tank systems vary considerably:
  - Were you to believe the most pessimistic views, then the vast majority of tanks are not maintained adequately or maintained at all; the installation is unsatisfactory in 80% of cases; and the designs of systems are unsatisfactory in a majority of cases.
  - Were you to believe the most optimistic views, then tanks are generally well maintained and in good conditions, although problems do still occur. Optimists also believe that maintenance is easy and householders should be able to do it themselves.
- The general view is that something needs to change in order to improve the management of rainwater tanks, recognising it is a considerable sunk investment (~$1 billion) that should bring value now and into the future.
- The vast majority of people think that the responsibility for maintaining tanks should stay with the homeowner. However, inspections may be done by someone different, and government may play a role in supporting householders in their efforts to maintain tanks.
- The key failure modes for rainwater tanks are, in order of importance: broken mosquito meshing, broken or inoperable pumps, blocked gutters, and structural failure of tanks.

- Indications are that households are likely to pay in the order of $20-$150 annually for the maintenance of their tanks. Some householders are unwilling to pay anything, and there are good reasons to argue that it should be a voluntary fee.
- Estimates of rates of failures are: pumps/parts being a problem in ~35% of cases; structural integrity being a problem in ~7% of cases; mosquitoes being a problem in ~22% of cases; and water quality being a problem in ~22% of cases.
- The key cause for such failures is lack of, or inadequate, maintenance. Other causes which also contribute to occurrence of such failures are design problems, incorrect maintenance and poor installation.
- Indications are that tanks need to be inspected and maintained on at least an annual basis to ensure a tank system in good condition, but preferably with more frequent inspections.

Finally, some key points coming out of the first phase of the study are: 1) that there is inadequate information regarding: the condition of the existing asset stock; 2) that the related public health risks for the stock is a concern; and 3) that there is a concern regarding the expected water savings from the use of rainwater tanks. The research team has subsequently been working with industry to collect data on the condition of rainwater tanks and to assist with the subsequent questions.

3.2. Stakeholder Workshop

A professional workshop was held in November 2011 at the Ecosciences Precinct, Brisbane, and is further described in Walton *et al.* (2012). A list of 34 potential participants was developed to include stakeholders from across five different sectors that we had identified in previous research as being involved in the rainwater tank management cycle (Moglia *et al.*, 2011): State Government (Queensland Health (QH), Department of Local Government and Planning (DLGP), Department of Environment and Resource Management (DERM), and various other departments); regulatory entities (Queensland Water Commission); utility companies (Queensland Urban Utilities (QUU)); local councils (Gold Coast, Redlands, etc); and industry (including engineering consultants, manufacturers and plumbers). Thirty of the invited participants were able to attend and only four were unable to attend on the day. The participants were not provided with any incentive to attend. To prepare for the workshop, participants were provided some background material, including an overview of the purpose of the workshop.

The workshop occurred over four hours of tightly scheduled activities:

1. Developing a shared understanding of the problem of rainwater tank management, by means of presentations and follow up discussion and questions.
2. Brainstorming a number of different ideas for which to undertake rainwater tank management. This task was done in smaller breakout groups, each facilitated by a member of the research team.
3. Classifying the ideas into broad categories of management approaches. This was done in the bigger group setting, facilitated by a member of the research team.
4. Analysing each of the strategic ideas in some depth, based on discussions in smaller groups. Each group analysed two chosen strategy categories from the previous session (hence only strategy options 1-5B in Table 1 analysed), focussing on benefits and barriers, implementation issues, and perceptions of difficulty and effectiveness. To keep participants on track, the analysis was based around a template of six questions.
5. Reporting back on the analysis to all workshop participants, allowing for broader group discussion on the topics. The groups then located each of the ideas on a two-dimensional conceptual map, which summarised the strategy in terms of its first dimension, ease of implementation (*Easy* to *Hard*) and as the second dimension, its judged impact on rainwater tank maintenance (*Effective* to *Ineffective*). The final conceptual map is shown in Figure 2.
6. Voting on the identified strategies, to give an idea of the preferences of participants. Each participant was asked to indicate three preferences, two strategies that they liked the most and

one strategy that they liked the least. The most preferred and the least preferred were colour coded with yellow and red stickers accordingly. Each participant placed his or her stickers on the relevant strategies on the public positioning map. The sums of preference scores for each strategy (+1 for yellow sticker, -1 for red sticker) are also shown in Figure 2.

Table 1: Workshop strategy ideas after categorisation (step 3 in workshop process).

Strategy Ideas
Leave it to householders to manage for themselves; the status quo
Leave it to householders, but provide them with support
Advice on what's to be done; fact sheets; helpline; directory of plumbers and tank cleaning services
Leave it to householders, but increase householder awareness
Promote benefits of keeping a tank maintained; highlight the consequences of not keeping a tank maintained; reminders and prompts
Home service, like Climate Smart - you pay to have someone come and inspect your tank
Create a register of tanks – rely on tank owners' cooperation
Create a register of tanks – make it compulsory to have tanks registered
Inspect tanks – make it compulsory to have your tank inspected when it is first installed; to check it has been installed properly
Inspect tanks – make it compulsory to have your tank inspected every couple of years
Inspect tanks – make it compulsory to have your tank inspected when your house is sold
Tank design – make it compulsory to improve the design of the tank so that less things will need maintaining
Maintenance information – make it compulsory to be given information about tank maintenance when you have it installed

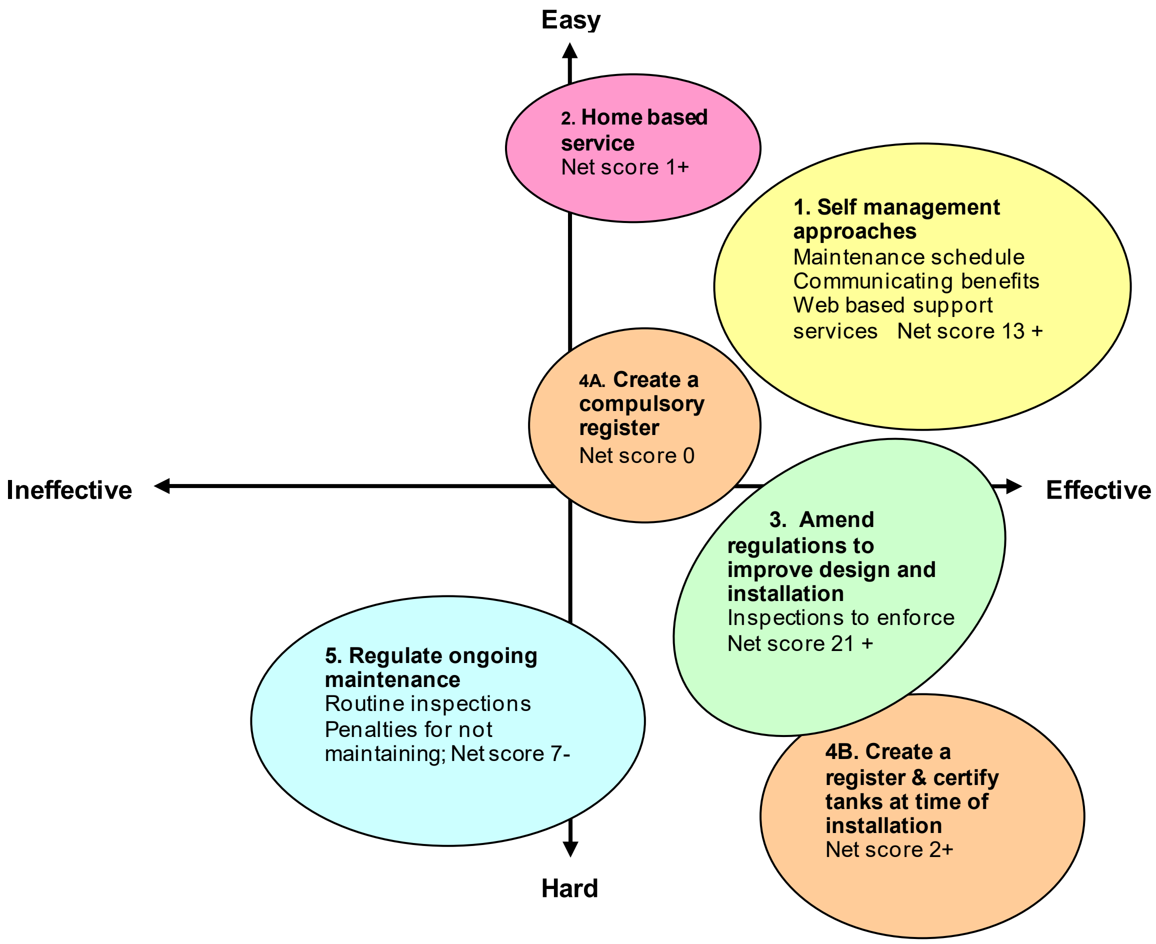


Figure 2: Conceptual map showing participants' judgments options for management.

The various options are described in the Appendix A, as extracted from the workshop report (Walton *et al.*, 2012).

3.3. Community Focus Groups

The community focus groups are further described by Walton *et al.* (2012). The aims of the community focus groups were to explore the questions:

RQ1. What are the views and attitudes of the community towards the various policy options for rainwater tank system management, as per Table 1?

RQ2. What are community members' preferred options for ensuring the ongoing performance of household rainwater tanks?

The qualitative research approach was chosen in an endeavour to gain a deeper understanding of the how the community thinks about rainwater tank maintenance and may respond to various management strategies. This allows for setting up a hypothesised model describing the motivation for maintenance as well as the transition from a motivation to maintain a tank to actually maintaining a tank.

Focus groups are considered by social researchers to be a good approach for exploring a targeted topic (Hair *et al.*, 2008). Focus groups are interactive in nature, allowing the discussions to be relatively unconstrained by the format. This is thought to generate a diversity of views, and to highlight differences in views within groups as well as between groups (Flick, 2010; Hair *et al.*, 2008).

Six focus groups were held over three evenings in November 2011. A total of 40 individuals participated in the focus groups. Individuals were targeted and recruited by a market research company, on the basis of the company database. The criteria for targeting individuals were to include 14 participants in each of three study groups: retro-fitted tank owners, mandated tank owners and non-tank owners. It was also considered important to have an even distribution of males and females, as well as a diversity of age. A mix of working and non-working individuals was another criterion. All participants lived in the Brisbane region and were offered $70 as a payment for their time and their travel expenses. Two invited participants did not attend. Within the focus groups, participants were divided into two smaller groups, where each group had six or seven participants. Each smaller group was facilitated by a researcher.

A semi-structured protocol was followed in the focus groups based around discussing a number of possible management strategies (see Walton *et al.*, 2012). Each session lasted approximately 90 minutes and was taped and later transcribed. The recorded data was transcribed and analysed using thematic content analysis. Related themes were combined, and seven groups of factors emerged as important to rainwater tank maintenance.

From the perspective of this report, a key output of the analysis of the focus group data was a model for describing the motivation for maintenance as well as the transition from a motivation to maintain a tank to actually maintaining a tank (see Figure 5). The factors of this model are further described in Appendix B.

Other important points in regards to the attitudes towards possible management strategies are:

- The community viewed any attempts to create a register of tanks very negatively and it was argued that it could lead to people abandoning their tanks. It was also thought that it would be a costly exercise with little benefit. However, a register may be supported if it was essential for public health reasons.
- There is strong support for self-management approaches as well as improvements to design and installation standards. Many thought that "do it yourself" information would be very useful, especially if combined with an effective communication program.

There were some minor differences in the views of the three groups, but results are relatively consistent regarding the above two points.

3.4. Follow-Up Interviews and Surveys

A number of follow up interviews were undertaken to collect the following information:

- Statements of requirements for what criteria should define "*successful rainwater tank management*". For this purpose, we interviewed individuals at QH, the QWC and the former DERM.
- Judgments about what contributes to a tank in good condition, i.e., those with knowledge in design, installation and maintenance. For this purpose we interviewed selected engineering consultants, manufacturers, and plumbing instructors.

3.4.1. Criteria for Successful Rainwater Tank Management

Table 2 shows the criteria for successful rainwater tank management that were identified via interviews with the key stakeholders.

Table 2: Criteria for successful rainwater tank management.

Criteria	Details
A. Adequate water savings	At least 90% of tanks need to provide the projected water savings from now and into the future. From a water planning perspective, this also needs to be certain fact, backed up by sampling of the condition of tanks and statistical analysis of the condition data (criterion D).
B. Acceptable low risk of mosquito breeding in tank systems	In the context of SEQ, at least 99% of tanks need to be protected by mosquito meshing, and the amount of stagnant open water needs to be kept to a minimum.
C. Acceptable low risk of health risks related to poor drinking water quality	Stakeholders consider that it will be impossible to ensure drinking water quality at an adequate level with adequate certainty. Information campaigns need to ensure that the community are advised not to drink untreated rainwater.
D. Knowledge of the condition of tanks	It was argued by the key stakeholders that the condition of tanks needs to be known. Not all tanks need to be sampled, but an adequate number of randomly selected tanks need to be inspected. Adequate water savings need to be assessed every 3-5 years, and acceptable low health risks need to be assessed on an on-going basis every year. To support the inspection program, there is a need for criterion E, knowledge of the tank stock.
E. Knowledge of the tank stock	In order to undertake a program of random inspections of rainwater tanks, there needs to be a database of tanks and their locations. Currently this type of information is managed by local councils, but there is a need to centralise this dataset into a single location.

As noted in the Table 2, a population of tanks in good condition is not a necessary requirement for key stakeholders' approval of the rainwater tank management. In addition to the tanks being in good condition, it is also critical that key stakeholders know that this is the case. As identified via interviews, QH need to know, via random inspections of tanks, on an annual cycle, that 99% of tanks are intact and do not provide opportunities for mosquitoes breeding. Furthermore, the QWC needs to have certainty, every 3-5 years, that 90% of tanks provide the expected water savings.

An important point here is that the key stakeholders have different requirements e.g. QH and QWC. Therefore, successful tank management as described by key stakeholders is made up of health factors (B and C) and water supply factors (A) and this will be delivered by a program described by criteria D and E, as described later in this report.

3.4.2. Judgments on what Contributes to Tanks in Good Condition

Interviews were also undertaken with professionals to collect judgments relating to a strategy that should lead to having tanks that are in good condition. As shown in Figure 3, adequate maintenance, adequate design, and adequate installation are requirements of a management strategy. This comes from the following clear statements from professionals in interviews:

- A tank with poor maintenance is likely to be in poor condition, regardless of good design and installation.
- A tank with poor design is likely to be in poor condition, regardless of proper maintenance and installation.
- A tank with poor installation is likely to be in poor condition regardless of satisfactory design and maintenance.

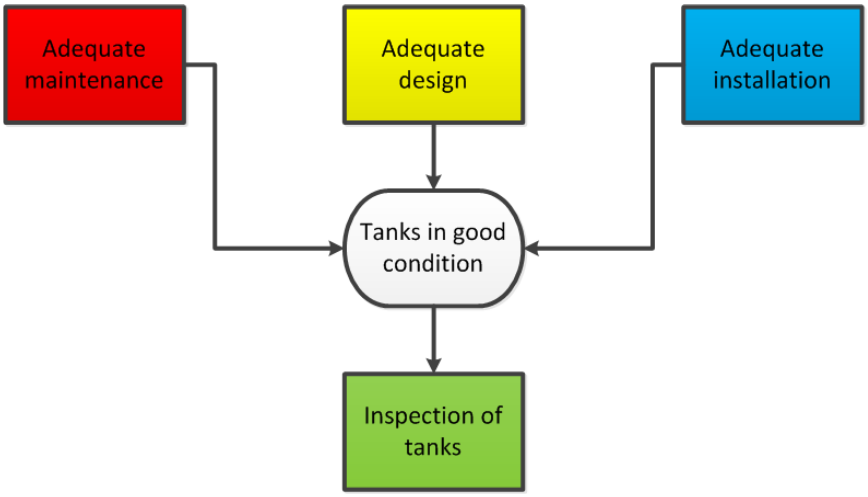


Figure 3: Three-phase management of rainwater tanks.

Quantitative judgments were also sought from selected interview participants, and these have contributed to the Conditional Probability Tables (CPTs) shown in Appendix C.

4. BAYESIAN NETWORK MODELLING

To evaluate the likely effectiveness of strategies for rainwater tank management, existing data, judgments and understanding have been used to formulate, calibrate and parameterise a Bayesian Network (BN) model which was developed to calculate the likelihood of effective strategies. The effectiveness is defined as the achievement of goals that have been identified in the interviews, i.e., criteria A-E in Table 2.

4.1. Theory of Bayesian Networks

The use of BN models is common in the field of integrated water management contexts (Bromley, 2006; Henriksen *et al.*, 2007; Ticehurst *et al.*, 2007). BNs are based on what is called plausible reasoning which is based on probability theory (Castelletti and Soncini-Sessa, 2007). The term Bayesian is based on the framework by Pearl (1988) and applies Bayes theorem for conditional probabilities. Computationally, BNs are made up of a series of nodes (representing factors) and directed arcs (representing causal links between factors) creating an acyclic graph. Causal links are represented by conditional probabilities. The repeated application of Bayes theorem using such conditional probabilities generates a system of equations. This system of equations can be solved to provide the probability distributions of all model factors.

To define the system of equations, BNs require identification of factors and their possible states, specification of a network structure, quantification of a conditional probability table (representing the causal links in the model), and finally probability tables with data on the likelihood of initial conditions. There are a number of commercial software packages for undertaking BN analysis with relative ease, such as Netica or Metafuze, assuming a basic understanding of uncertainty and probability theory. A simple example of a Bayesian Network is shown in Text Box 1.

Text Box 1. Example of a Bayesian Network for the purpose of illustrating the method.

A game of soccer can have three outcomes: 1) Team A wins, 2) Team B wins, and 3) Teams A and B draw.

We would like to find out the likelihood of these three outcomes. We also know that the current form of the team critically impacts on the outcome.

The conditional probability table, if the current form is known, is as follows:

Team A Form	Team B Form	Team A Win	Team B Win	Draw
Good	Good	40	20	40
Good	Bad	80	10	10
Good	Average	60	20	20
Bad	Good	20	60	20
Bad	Bad	40	20	40
Bad	Average	60	20	20
Average	Good	30	40	30
Average	Bad	60	20	20
Average	Average	40	20	40

The table shows the probability distribution (i.e. probabilities of Team A win, Team B win or draw) in the circumstances that we know the current forms of the teams as per column 1 and column 2.

We furthermore know that the team A is in good form 60% of the time, in bad form 20% of the time and in average form about 20% of the time. Similarly we know that the team B is in good form 30% of the time, in bad form 30% of the time and in average form about 40% of the time.

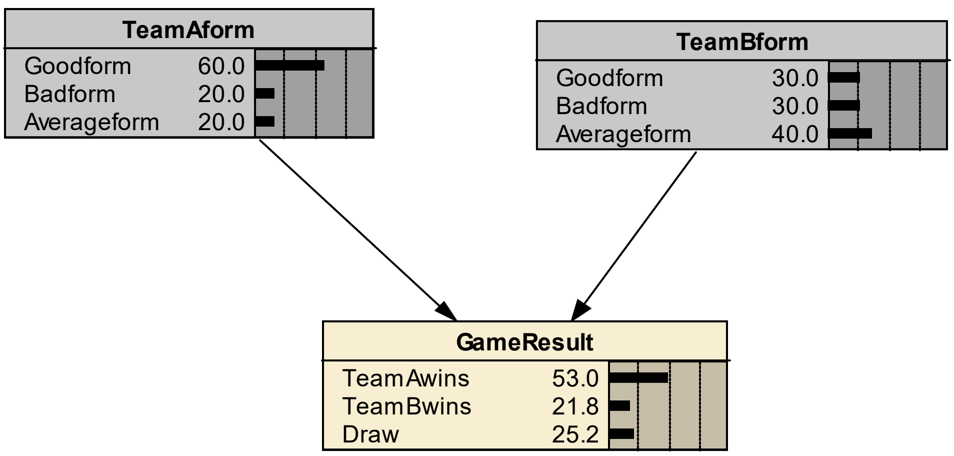
Based on Bayes theorem and basic probability theory, we can now calculate the likely outcome of the game between team A and team B.

If we know nothing about the teams' forms, then the following:

P(Team A wins) = 0.53 % the probability that team A wins is 53%
P(Team B wins) = 0.22 % the probability that team B wins is 22%
P(Draw) = 0.25 % the probability of a draw is 25%

These are the baseline probabilities, in the case that we don't know anything about the current form of the two teams.

When we do know something about the current form, we can get the likelihoods from the table above. The graphical representation of this Bayesian Network is shown in the figure below.



4.2. Definition of the Model Structure

The starting point of the BN model is the criteria that have been identified by QWC and QH (see section 3.4.1). The model has been constructed by identifying cause-and-effect relationships. The identification of cause-and-effect relationship has been done by identifying all the factors that influences outcomes, or that have a causal effect on the likelihood of outcomes. Such cause-and-effect relationships are defined through the following statements:

- A strategy is effective if QWC and QH are satisfied with it.
- The QWC is happy with a strategy if it knows that rainwater tank systems provide water savings, because this means it can postpone certain water supply investments. This depends on two conditions:
  - Adequate knowledge of tank system condition.
  - Adequate tank system condition in 90% of cases, from a water savings perspective.
- QH is happy with a strategy if it knows that rainwater tanks do not pose a mosquito related health risk to the community. This depends on two conditions:
  - Adequate knowledge of tank system condition.
  - Adequate tank system condition in 99% of cases, from a health perspective.
- Knowledge of the condition of the tank stock is generated by means of:
  - Having a good and well structured knowledge of where the tanks are installed, preferably in a well designed centralised database.
  - Regular inspection program of tanks, specifically regarding water savings potential and health concerns, carried out in a manner ensuring statistical confidence in results.
- A tank's capacity to reach its potential for water savings depends on the physical condition of the tank system. Specifically, it depends mostly on the condition of the pump.
- A tank's risk of having mosquitoes breeding in it depends on the physical condition of the tank system. Specifically, it depends mostly on the presence and integrity of the mosquito meshing.
- The condition of tanks depends on the quality of how the tank system has been installed, the adequacy of the tank system design, and the adequate maintenance of tanks (Figure 3).
- The maintenance of tanks depends on the householders' intention to maintain a tank (see section 3.3).
- The householders' intention to maintain a tank depends on the perceived benefits (see Appendix B1 and B3), the belief that is the right thing to do (see Appendix B5), the self identify (see Appendix B6), and the efficacy (see Appendix B4) of householders.

These statements define the probabilistic causal relationships that develop the BN model (shown in Figure 4). In this figure, boxes represent factors, arrows represent probabilistic causal relationships, words in boxes represent possible states of each factor, and numbers represent the probability (as a %) of a factor being in a given state.

The factors and their states are shown in Table 3.

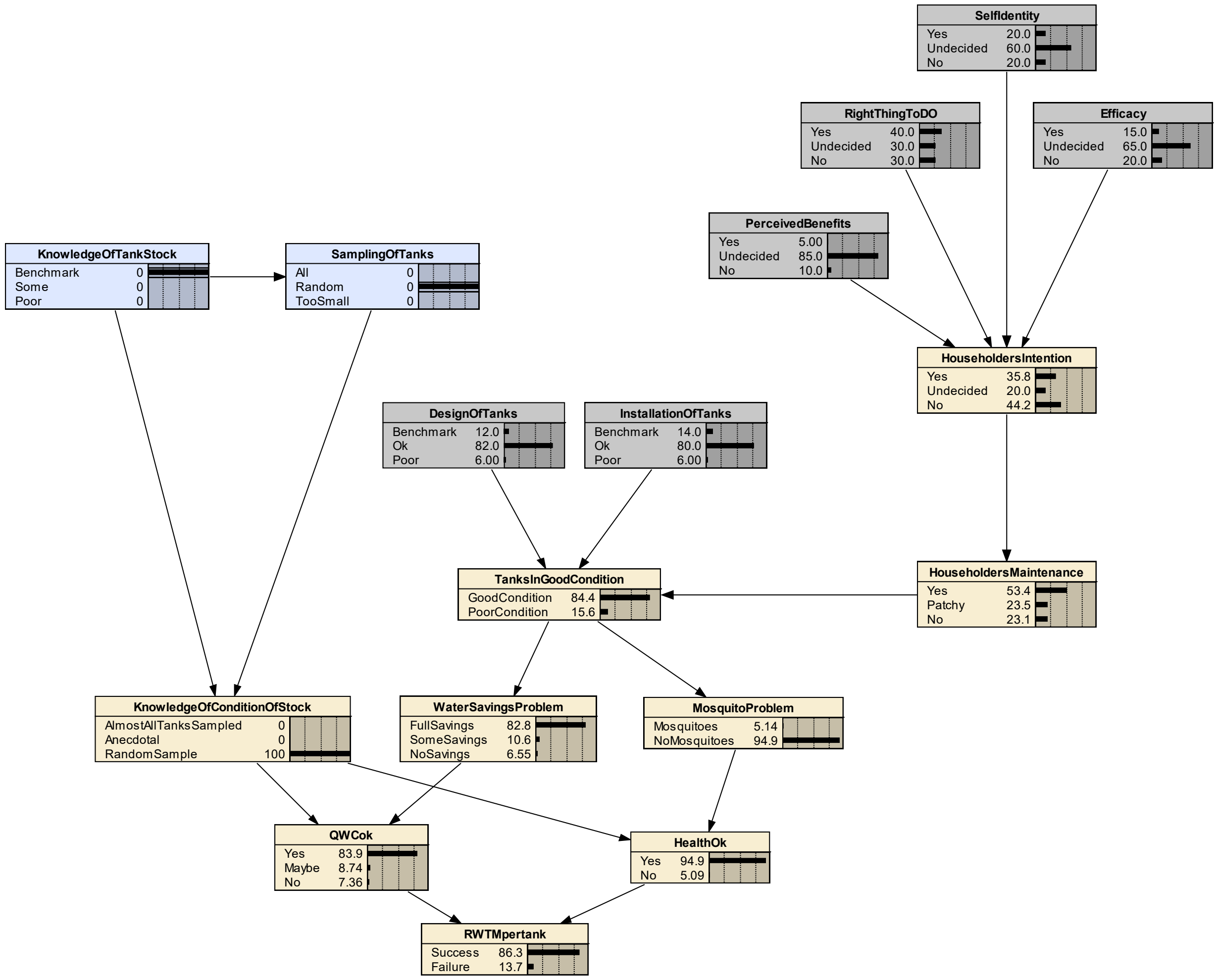


Figure 4: BN model of the effectiveness of rainwater tank management strategies.

Table 3: Model factors and their states.

Factor	Possible States / Outcomes
RWTM per tank: describing whether an individual tank is aligned with the goals of QWC and QH	• Success, i.e. criteria are met • Failure, i.e. criteria are not met
QWC ok: describing whether the goals of QWC are met, for an individual tank.	• Yes, i.e. goals are met. • Maybe, i.e. unclear whether goals are met • No, i.e. goals are not met
Health Ok: describing whether the goals of Queensland Health are met.	• Yes, i.e. goals are met. • Maybe, i.e. unclear whether goals are met • No, i.e. goals are not met
Knowledge Of Conditions Of Stock: describing what level of knowledge that exists about the population of rainwater tanks.	• Almost all tanks sampled. • Anecdotal, i.e. some information about condition of tanks is known but information is available in an ad hoc and unorganised way without an assurance about the statistical significance about the estimates of fault rates. • Random sample, tanks are inspected to provide a high level of statistical significance associated with key estimates of fault rates in the tank population.
Sampling of tanks	• All, i.e. every single tank sampled • Random, i.e. a statistical based random sample of and adequate number of tanks. • Too small, i.e. only small number of tanks sampled.
Water Savings Problem	• Full savings, i.e. no fault with pumps or otherwise, that prevents the tank to provide predicted water savings. • Some savings, i.e. some fault that prevents the tank from achieving 100% of predicted savings, but which does not prevent the tank from working altogether. • No savings, i.e. a fault of the tank system that makes it inoperable.
Mosquito Problem	• Mosquitoes, i.e. breeding of mosquitoes in the tank • No mosquitoes, i.e. no breeding of mosquitoes in the tank
Tanks In Good Condition	• Good condition, i.e. no faults of tank • Poor condition, i.e. at least one fault in tank
Design Of Tanks	• Benchmark, i.e. designed as well as it could. • Ok, i.e. design is adequate but not perfect. • Poor, i.e. obvious faults in design
Installation Of Tanks	• Benchmark, i.e. installation carried out as well as is possible. • Ok, i.e. installation is adequate but not perfect. • Poor, i.e. obvious faults in installation.
Householders Maintenance	• Yes, householders undertake maintenance according to guidelines. • Patchy, householders undertake maintenance but not often enough. • No, householders undertake no maintenance.
Perceived Benefits, i.e. whether the householder perceives there to be benefits of having a tank	• Yes, if householder has this perception. • Undecided, if householder is not sure whether he/she agrees with this. • No, if householder does not have this perception.
Right Thing To Do, i.e. whether the householder thinks that having a tank is the right thing to do	
Self Identity, i.e. whether the householder sees him/herself as someone who keeps things in good repair	
Efficacy, i.e. the perception of being capable of maintaining the tank	

4.3. Parameter Estimation and Calibration of BN Model

In the BN model, each arrow is represented by a Conditional Probability Table (CPT), and each input node (i.e., a box in Figure 4 with no arrows into it) requires a probability distribution. The assigned CPTs and probability distributions are shown in Appendix C. Assigning these CPTs and probability distribution is the process of parameterising and calibrating the BN model. This has been done as per Table 4 and Table 5.

Table 4: Basis for BN model CPTs.

CPT Description	Basis for Calibration / Parameter Estimation
CPT-A. Probability of failure assuming tank condition	Plumbers' survey of reported rates of observed failure types for mandated and rebated tanks. Particularly relating to reported rates of problems with mosquito meshing, and problems with pumps.
CPT-B. Householder intention to maintaining a tank ***assuming*** Socio-psychological factors	Calibrated in a spreadsheet as an intermediate step between socio-psychological factors and observations of householder maintenance. In other words, probabilities were chosen to achieve householder maintenance distribution, with the estimated probability distribution of socio-psychological factors (on the basis of survey).
CPT-C. Tank condition, ***assuming*** maintenance, design and installation	Biermann *et al.* (2012) report that inspections of 223 tanks that found approximately 10% of pumps in less than good condition, and with judgments of professionals (253 surveyed), and judgments of plumbers (15 surveyed). Also, on the basis of the judgments by professionals and plumbers, maintenance has been defined as being approximately 3.2 times more important than design or installation. This table has been calibrated in a spreadsheet to achieve approximately 15% of tanks in poor condition, which is consistent with the small amount of data that is available. Effects of better design, installation and maintenance have been thought to be cumulative and calculated in a spreadsheet.
CPT-D. Water savings problems ***assuming*** condition of tanks	Defined on the basis of reported faults in tanks in poor condition. Tanks in good condition have been assumed to be largely providing full savings and a small number (5%) providing some savings, most likely due to minor issues like blocked gutters.
CPT-E. Mosquito problems ***assuming*** condition of tanks	Tanks in good condition are assumed to have no mosquito related problems, and on the basis of reported faults by plumbers, approximately 33% of tanks in poor condition are assumed to have problems with mosquitoes.
CPT-F. QWCok and HealthOk, ***assuming*** problems	These have been defined on the basis of stated preferences by these stakeholders.

Note: Calibration here refers to an ad-hoc but justified process of adjusting parameters in order to get the model to perform in certain ways. Parameter estimation is a more formal approach, typically based on statistical methodologies, for choosing parameter values.

Table 5: Basis for model input probability distributions.

Probability Distribution	Basis for Calibration / Parameterisation
Householder maintenance (used to calibrate conditional probability table CPT-B)	Based on responses in the survey of professionals in the previous year (Moglia *et al.* 2011; 253 professionals responded), a weighted average of responses was used to estimate the percentage, x, of tanks with adequate maintenance. The percentage of tanks with patchy or no maintenance is y=100%-x. Half of those tanks are considered to have no maintenance, and the other half are considered to have only inadequate (patchy) maintenance. Three cases as scenarios were identified and estimates provided for each case, i.e. the judgments by the group that were very optimistic (N/A group, see report Moglia *et al.* 2011), the government group that were very pessimistic, and finally the average group somewhere in between.
Problems in design or installation	The problems in installation or design were estimated on the basis of plumbers' survey (15 plumbers responded) results but adjusted to take into account that plumbers only see the bad cases. The adjustment has been done considering that the tanks that plumbers don't see are likely to be an estimated three times fewer problems than the tanks that they do see.
Socio-psychological factors (Table 23)	Input from survey of 533 householders with both mandated and retrofitted tanks conducted in May 2012 (Walton and Gardner 2012). The distribution has been set as per the frequency of scores for the items that measured each of those four constructs. The survey used a 1-7 scale with the higher number indicating the respondent agreed more strongly with the statement. • Scores that were 1-2.5 = No • Scores that were 3-4.5 = undecided • Scores that were 5-7 = Yes
Knowledge of tank stock	This is a decision node variable, so is set depending on which scenarios is being explored.
Sampling of tanks	This is a decision node variable, so is set depending on which scenarios is being explored.

4.4. Simulation: Screening of Strategic Options

In order to identify a strategy that will address the concerns of QH and QWC, a number of strategies will be entered into the BN model, in order to evaluate the predicted impact on water savings and risk of mosquito breeding in tanks. The strategies will be evaluated for a number of cases, ranging from the optimistic scenario to a plausibly realistic scenario, to the pessimistic scenario. Strategies were first defined individually, and in the second round strategy portfolios were explored.

Table 6: Scenarios for the purpose of sensitivity analysis.

Scenario	Description
Optimistic	• Installation and design approximately three times better than what plumbers report • Rates of adequate maintenance according to most optimistic group (N/A group)
Average	• Installation and design approximately two times better than what plumbers report • Rates of adequate maintenance according to average survey results
Pessimistic	• Installation and design approximately same as what plumbers report • Rates of adequate maintenance according to most pessimistic survey results (government group)

Table 7: Strategies for evaluation in the BN model.

Strategy	Desired Outcome
A. Improve designs	Rate of inadequate design reduced by 80%.
B. Improve installations	Rate of inadequate installation reduced by 80%.
C. Improve knowledge of tank stock	Setting knowledge of tank stock as benchmark.
D. Rigorous program of tank inspections	Setting sampling of tanks as random inspection program.
E. Campaign on promoting the benefits of tanks	Transferring 80% of those who are undecided to believe that there are benefits of having working tanks.
F. Improving householders' skills and ability to maintain tanks	Transferring 80% of those who are undecided to have the adequate skills and knowledge.
G. Enforcing the moral imperative of maintaining tanks	Transferring 80% of those who are undecided on whether rainwater tanks and maintaining them is the "right thing to do", i.e., enforcing the moral imperative.
H. Campaign to improve people's image of themselves as someone who maintains their possessions, and specifically their tanks	Transferring 30% of those who are undecided on whether they see themselves as someone who maintains their possessions, i.e. their tanks.

4.5. Simulation Results

To evaluate the likely impacts of the strategies in Table 7 on the likelihood of achieving desired outcomes, the BN model was applied and the results are shown in Table 8. It is clear from this table that the first step to be undertaken is adopting strategies C and D in combination. Without this, no strategy by itself is likely to achieve any great impact. For the second round of simulations, this strategy has been locked in.

Table 8: First round of simulation results.

Strategy	Condition Scenario	Rebated (R) or Mandated (M)	Installation and Design Judgments	Health OK?	Savings OK?	Strategy Success
Status quo	Average	Rebated	Optimistic	49%	40%	33%
A	Average	Rebated	Optimistic	49%	41%	33%
B	Average	Rebated	Optimistic	49%	41%	33%
C and D	Average	Rebated	Optimistic	93%	84%	85%
E	Average	Rebated	Optimistic	49%	41%	33%
F	Average	Rebated	Optimistic	49%	41%	33%
G	Average	Rebated	Optimistic	49%	41%	33%
H	Average	Rebated	Optimistic	49%	40%	33%

Table 8 shows that the main impact on the chance of achieving strategy success comes from having an on-going and rigorous inspection program to ensure that public health risks are managed, and that water planners can estimate the expected water savings from the rainwater tank systems that are installed in SEQ.

The second round of simulations, see Table 9, shows a somewhat problematic issue which is that there is very limited benefit of undertaking just one strategy at a time. It appears that there must be a multi-pronged approach. The first multi-pronged solution explored is to improve design and installation but even this does not provide a great benefit, according to the model. Finally all approaches together are tried to see if this can achieve some additional improvement in tank condition. In the end, only marginal improvements can be made to the overall likelihood of success.

Table 9 shows that in the optimistic case, the likelihood of achieving a successful rainwater tank management strategy is relatively high (85-88%) but that there remain some concerns relating to public health risks. However, please note that this was only for the relatively optimistic view on current state of installations and designs.

Table 9: Second round of simulation results with various combinations of strategies.

Strategy	Condition Scenario	Installation and Design Judgments	Tanks OK?	Health OK?	Savings OK?	Strategy Success
C and D	Average	Optimistic	84%	93%	84%	85%
C and D and A	Average	Optimistic	84%	94%	85%	86%
C and D and B	Average	Optimistic	84%	94%	85%	86%
C and D and E	Average	Optimistic	85%	94%	85%	86%
C and D and F	Average	Optimistic	85%	94%	85%	86%
C and D and G	Average	Optimistic	84%	93%	84%	85%
C and D and H	Average	Optimistic	84%	94%	85%	85%
ABCD	Average	Optimistic	84%	94%	85%	86%
ABCDEFGH	Average	Optimistic	85%	95%	87%	88%

Next, we explore what the results would look like in a pessimistic case on this issue. The third round of simulations (Table 10) has been undertaken with the assumption of the more realistic assessments of levels of adequate design, installation and maintenance (i.e. based on plumbers' judgments as well as pessimistic views in the professional survey). The results indicate a much lower likelihood of success being achieved, and unfortunately it seems that there is also little that can be done about the low performance levels.

Table 10: Third round of simulation results.

Strategy	Condition Scenario	Installation and Design Judgments	Tanks in Good Condition	Health OK?	Savings OK?	Strategy Success
C and D	Realistic	Realistic	71%	89	76	77
C and D and A	Realistic	Realistic	73%	90	77	78
C and D and B	Realistic	Realistic	73%	90	77	78
ABCD	Realistic	Realistic	75%	90	78	79
ABCDEFGH	Realistic	Realistic	76%	91	79	80

Table 10 shows the outcomes in a more realistic scenario, and the likelihood of a successful management strategy is lower than optimistic case (77-80%) and again there seems to be limited benefits of strategies other than an inspection program.

5. STRATEGY PORTFOLIO

The conclusions of the simulation results in the above section are:

1. The first and foremost priority needs to be to find out more about the location of tanks and to undertake a sampling program of their condition. This will help identify the extent of the health and water savings problems as well as enable statistical analysis that will help to better calibrate the BN model described above. This in turn will help identify what the next strategy needs to be, or whether rainwater tanks are in fact, if risk mitigation is impossible, too much of a health risk and that they should be abolished altogether. However, rainwater is not recommended for potable applications.
2. Achieving improvements in the rate of maintenance is difficult as it requires design, installation and O&M improvements. Getting adequate O&M seems very challenging. Furthermore, even when factors are changed there will always be people who are not interested in maintaining their tanks.
3. A critical component of the model which is also largely unknown is how the design, installation and maintenance combine to result in a tank that is in a good condition. No doubt there will be technologies and/or designs that can result in a tank that is in very little need of maintenance. Serious consideration needs to be put onto identifying and promoting good designs for tanks.

The rest of the report describes a way forward in trying to achieve better management of rainwater tanks in SEQ.

5.1. Gaining Knowledge of Tanks and Inspecting Tanks

In the effort to increase the chances of success of a rainwater tank strategy, as it has been defined in the prior text, by far the most effective first step is to improve the knowledge of the condition of tanks. This would also provide an information source for policy makers and managers to better understand which factors would contribute to a rainwater tank being in a good condition, and hence to be in a position to target further activities in an effective and informed manner.

Currently, the responsibility of undertaking random inspections to ensure public health requirements is with local councils. However, the general view that has emerged through interviews and stakeholder engagement is that local councils are under-resourced and an inspection program for tanks is not a key priority for many councils. The records of the results of such inspections are also not kept in a centralised location, and this makes structured and systematic analysis of the tank system condition data virtually an impossible task across the SEQ region.

Furthermore, even the location of all rainwater tanks is not widely known, and any estimates of how many tanks exist in the SEQ region are based on sampling, for example via the census by the Australian Bureau of Statistics. In theory, rebated tanks have associated property information and State and/or local government should have some information (for those tanks linked to a rebate at least), and data owners may not be willing or able to share such information. Furthermore, information is dispersed and requires updating and monitoring; and access to this data is difficult. Surveys of tank owners have had to rely on contacting households who ought to have a tank, such as for example inferred based on the construction date of the house. Clearly, designing a structured program for inspecting the condition of tanks is a difficult task, and discussions need to occur about what agency is best placed to undertake such inspection programs.

There have been some efforts to gather information from local councils about the location and the condition of tanks. However, interviewees have reported considerable difficulties in this task. It appears the task required for achieving this goal would be:

1. Collecting information about the location of rainwater tanks, either via council records, or by contacting households directly. Community focus group results indicate that the first option is much preferred because asking the community for this information is likely to be perceived as a government failure to keep appropriate records, regardless of whether government is mandated to do so or not.
2. Storing the rainwater tank information in a well designed and secure database, preferably available over the internet so that the appropriate stakeholders can access the data for their various needs (i.e., for designing condition sampling programs, to estimate potential water savings in different areas, and to be able to send targeted communications to tank owners). Such data would form the basis of an effective asset management strategy.
3. Inspecting tanks on a regular basis to evaluate tank condition compliance and to help design targeted programs towards improving the condition of the asset stock. The most urgent need for inspections comes from the requirement to ensure public health. This is particularly the case in the current situation where the overall public health risk related to rainwater tanks is largely unknown. However, research is being conducted in SEQ to understand the micro biological aspects of rainwater quality and assess the health risk associated with fit for purpose use.

5.1.1. Centralising the Data on Tanks

Collecting data on the presence, type and condition of tank systems into one well structured database is a critical step to allow for the effective management of tank systems. However, this needs to be done in a way that is sensitive to community attitudes, and to ensure that the effort is not perceived as 'heavy handed'. The focus groups have also indicated that community members are generally surprised that the State Government does not already have this information in a readily available format.

Furthermore, on the basis of the focus group results, it will be critical to justify these efforts as 'being proactive' about managing health risks related to mosquito borne disease and drinking water quality. This is also appropriate since a main purpose of better rainwater tank management is exactly that.

On the basis of the stated criteria for a successful management strategy by key stakeholders, the requirements for the database system are shown in Table 11, although the exact scope of the database would need to considerer the regulatory environment.

Table 11: Requirements of database system.

Requirement	Level of Need*
Information on the location of the systems (i.e. street address)	Critical
Information on condition inspection results	Critical
Information on rebated / mandated tank system	Critical
Available online for users with approved access (ie. councils and state government departments)	Critical
Information on whether the system is internally plumbed	Critical
Type of system (above ground, below ground, etc)	Useful
Information on the connected roof size	Useful
Year or date of installation of the system	Useful
Size of the tank	Useful

***Note**: a critical requirement is one that must be in place in order for the database to be effective in its desired tasks, whilst a useful requirement is one that is likely to impact on the performance of the database, in terms of its capacity to achieve goals.

With an estimated 300,000 tanks, and assuming that the database is set up in a SQL Server and based on labour cost estimates by IT professionals in the CSIRO, the cost to create the database system would be approximately $205,000-345,000 (see Table 12). As a rough estimate, there would also be approximately $65,000 per year additional cost for ongoing database maintenance; excluding efforts to keep property ownership up to date. In addition to setting up the database itself, the main effort of centralising all the tank system data would be to collect all the known tank information systems into a single system and that would involve engaging with councils to identify and collect information, as well digitising paper-based information, and to enter information into the database.

Table 12: Cost estimates for database system.

Initial Cost Item	Approximate Cost in $
SQL Server software purchase (if departments do not already have a license).	$10,000
Database design and software implementation (0.25 FTE) including overheads and other on-costs (conservative estimate)	$65,000
Collecting, digitizing and entering data into database (0.5-1.0 FTE)	$130,000-$260,000
Total (range) – excluding annual database management	$205,000-$345,000
Ongoing Cost Items	**Approximate Cost in $**
On-going database maintenance annually (0.25 FTE)	$65,000

If the database system interface is implemented in HTML5, it should be possible to have it accessible on phones and the web, allowing plumbers, householders and councils to directly enter information into the database. If this is linked to a mass media campaign, it might be a very effective way of collecting the data.

5.1.2. Inspections Program

Tank system inspections are already carried out just after the installation of tank systems as part of the certification process (see Text Box 2), or by householders themselves or by calling out a plumber. The types of activities that may be included in a tank system inspection and repair are shown in Table 13.

Table 13: Tank system components and maintenance activities.

Tank System Component	Activity	Importance*
A. First flush	Inspect / clean / repair	Useful
B. Gutter	Inspect / clean / repair	Critical
C. Mosquito screen	Inspect / clean / repair	Critical
D. Roof and flashing	Inspect / repair	Useful
E. Animals / pests	Inspect / remove	Useful
F. Water quality	Identify and remove the cause	Critical
G. Rainwater tap signage	Inspect / repair / replace	Useful
H. Pump	Inspect / repair / replace	Critical
I. Filter	Inspect / repair / replace	Useful
J. Sediments in tank	Inspect / remove	Useful

***Note**: a critical component is one that must be maintained in order for the tank to achieve adequate performance. A useful component is one that can or may impact on the performance of tanks, or the health risks associated with tanks.

From the perspective of achieving water savings and managing the risk of mosquito borne disease, the two most critical aspects are C and H (as per Table 13). Based on information from plumbing professionals; it should be possible to inspect the tank components A-I at a cost of approximately $50-$150 per tank. Checking and removing sediments in the tank can be done for approximately $150-$200 per tank but is only required once every two to three years (or perhaps even more infrequently than this).

The key driver for the inspection program is to ensure that mosquito related risk is adequately low. To ensure this risk is being minimised, the approximate guideline is that QH needs to know that there is 99% compliance with the mosquito meshing requirement, and that this has been established with an error margin of +- 1%. Using basic probability theory, a sample size of 1164 would be required to achieve this relatively accurate estimate. This has been estimated by describing the number of tanks with adequate mosquito meshing using a Binomial distribution and by applying a Normal approximation and a conservative estimate of the rate of non-compliance at 3%. If the rate of non-compliance is 5%, the sample size would need to be 1,900 in order to achieve the +-1% error margin. If the same calculation is being used for estimating the required sample size for water savings (using an assumed conservative non-compliance at 20%, and a required error margin of +-3%), the required sample size is 700.

Using these estimates of sample size in order to reach a required level of confidence in the estimates of non-compliance, we identify that approximately 1,200 tanks need to be inspected each year. With a conservative estimate of the cost of one inspection, the cost of this program would range between $60,000 and $180,000 per annum. When normalised to a per tank basis (~300,000 tanks across SEQ), this cost is approximately $0.2-0.6 per tank per annum.

Text Box 2. An example of post-installation certification inspections by council.

Inspections are conducted in stages

Stage 1) Inspection of pipe work and framework – specifically, it is ensured that cold taps are connected to toilets and washing machines.

Stage 2) Second and final inspections are conducted near the completion of house construction where they check if pipe work and pumps are installed. They also nominate where the garden taps are (ensure there is at least 1 outdoor tap) and it is identified on the wall.

Compliance certificate is issued for the entire house

It takes around 15-20 minutes for inspections including the inspection, administrative work and issuing of the certificate.

The details are entered on a hard copy file and then scanned onto the system later at the office. Some may document the inspection in an electronic format.

We note that the scope of such inspections could be extended to incorporate issues relating to the broader goals of rainwater tank management, i.e. to ensure water savings are made, and that the tanks do not pose threats to public health.

5.2. Promoting Good Design

In the spirit of the holistic approach that is necessary for the management of rainwater tanks, it has been identified throughout interviews and literature reviews, as well as in surveys and observations by plumbers, that tank system design is a key factor in ensuring their good condition over time. Because of the limited scope of this study, we are not in a position to identify in detail what type of designs ought to be used. However, a series of design principles are proposed based on feedback and suggestions received during the course of the research from plumbing professionals and raintank industry representatives.

5.2.1. The Problems of Current Design

Rainwater systems currently sold in the market are available in a wide range of configurations, with the potential for selection of myriad designs, materials and shapes for raintanks and components. Feedback from representatives of the plumbing industry indicates that there is significant variability in the design of type of fixtures installed in rainwater tanks and that there is considerable variability in performance, ease of access or ease of removal for such fixtures.

The Rainwater Tank Design and Installation Handbook (Standards Australia, 2008) is the key reference document for development of rainwater systems. It was developed by the Australian Rainwater Industry (ARID) and the Master Plumbers and Mechanical Services Association of Australia (MPMSAA) and outlines the minimum standards in place at the time of publication.

A number of Australian standards are in place to ensure that the minimum integrity of rainwater harvesting system components is achieved, as shown in Table 14. These standards specify the minimum requirements to ensure structural integrity, performance stability (durability), safety (chemical stability, protection against vectors, ingress of children, debris, unauthorised entry) and functionality for tanks and components. The standards are not designed, however, to address the particularities in the design of rainwater system ancillary components such as leafguards, first flush diverters, etc. Nor have they been designed to promote the best practices when it comes to component design.

This gives manufacturers the freedom to develop ancillary parts and components and hence to differentiate their products. Feedback from plumbing professionals indicates that there is significant variability in the products offered in the market. However, guidance on how to benchmark product effectiveness is lacking and most tank owners have limited awareness of product differences.

Feedback from surveys and from industry representatives indicates that, among the various tank systems, there have been a number of components plagued either by poor design regarding maintenance (difficult to access or difficult to clean), durability or inferior quality (e.g., broken mosquito screens, or failure of tanks at seams). At the same time, the professionals have also highlighted that there are also good quality products available in the market at a competitive price that fulfil their intended purpose and are easy to maintain.

Much of the criticism and the reports of failure of tanks for improper design referred to the time when rebates for rainwater tanks were provided and the market was quickly inundated by all types, products and designs. Since that time, the quality of products has been reported to improve to a degree.

One of the key issues targeted in this research has been ease of tank system maintenance by householders given the need for long-term functionality of rainwater systems. Yet, ease of maintenance has to date not been one of the key criteria addressed in the development of standards.

Thus, it is up to the industry and to relevant stakeholders to consider the value of promoting product design best practices that may facilitate the maintenance and upkeep of such systems.

Table 14: Standards and guidelines applicable to rainwater harvesting systems.

Component	Standards	Requirements
Rainwater tanks	AS/NZS 4766:2006 Polyethylene storage tanks for water and chemicals AS/NZS 5200.000 Rainwater tanks lined with approved coatings AS2001 Methods for test of textiles (flexible tanks, bladders) AS 2180 Metal rainwater goods –Selection and installation AS3735 Concrete structures retaining liquids	Structural integrity Thermal and UV stability Contact with water Water tightness
Components	ATS5200.466 2004 : Technical Specification for plumbing and drainage products - Rainwater tank connection devices ATS 5200.467-2004 : Technical Specification for plumbing and drainage products - Rainwater tank connection valve ATS5200.026 Cold water storage tanks AS5200 Technical specification for plumbing and drainage products AS/NZS 3500.1 and .3 Pipes, outlets and fittings for supply of rainwater	Design(compliance with relevant standards) Chemical stability in water Hydraulic strength Watertightness Endurance
	AS4020 Testing of products for use in contact with drinking water	Chemical stability in water

Component	Standards	Requirements
Openings in tanks	HB230-2008 Rainwater tank design and installation handbook	Designed for human load bearing Secured to prevent entry of children, animals, insects, surface water, groundwater and rubbish. Water tightness Requirement for insect and vermin control (including mosquito prevention) Allowance for tank access Prevention of light penetration
Stormwater roof drainage	AS/NZS 3500.3 Plumbing and drainage stormwater drainage	
Rainwater tank overflow – point of discharge	AS/NZS 3500.3 Plumbing and drainage stormwater drainage	
Rainwater tank connection devices in contact with network utility drinking water	AS 5200.000.2006 Technical specifications for plumbing and drainage products-Procedures for certification of plumbing an drainage products ATS 5200.466 Technical specifications for plumbing an drainage products - Raintank connection devices ATS 5200.467 Technical specifications for plumbing an drainage products - Raintank connection valve Need to be Watermark certified	Certification requirements
Pumps	AS/NZS 3500.1 minimum pressure 50kPa at the minimum flow rate required. AS2417.1 2001 Roto-dynamics pumps-Hydraulic performance acceptance tests AS/NZS 60335.2.41 Electrical safety AS/NZS CISPR 14.1 Electromagnetic compatibility	Performance (head, pressure)

5.2.2. Recommendations for Promoting Good Design

The main concern for rainwater tanks maintenance has been mosquito breeding, due to the risk of public health, often associated with removal or damage to screens by uninformed or uninterested householders. Damage to screens has been attributed mostly to breaks due to inferior design or material, whilst screen removal has been attributed mostly to householders trying to increase flow into tanks.

Therefore a mosquito screen or an opening screen has to address two major issues. It needs to allow ease of cleaning or removal of debris by householders to prevent blockage. It also needs to prevent tampering by uninformed householders. Thus the options would be to design and use:

- Self-cleaning screens;
- Screening that are easy to clean without removal; or
- Screens that can be removed and are easy to clean but which require some effort (e.g., tools) for removal, and that have warnings about the public health risks, and possible legal implications of removing the screen.

The second key concern leading to significant decrease in a rainwater tank system's potential for water savings is pump failure. When pumps break down, the water supply is interrupted until they are repaired or replaced. Whilst there is most likely a range of reasons for why pumps break down, two likely common explanations have been highlighted in the research:

- Pumps are of variable quality, and the cheaper range of pumps, are reported to be more likely to break down than others. This is anecdotal information and further investigation is required to establish whether this is in fact the case.
- Pumps are sometimes of inadequate capacity or type for the task. A pump for a rainwater tank system will often run outside of its most energy efficient operational range. If this has an impact on the longevity of a pump, the appropriate sizing and choice of pump will have an effect on the expected lifetime of a pump.

Review and evaluation of the reliability of different pumps for different operating conditions will be of critical importance for ensuring the longevity of tank systems.

Reducing maintenance requirements for rainwater systems can also be promoted through holistic design of the tank system from source to supply. For example, design of gutter guards, first flush diverters, leaf guards and screens all contribute to reducing the volume of debris that reach a tank.

The recommendations for promoting good designs of rainwater tank systems in SEQ are:

1. Review of the reliability and longevity of products in the markets, in view of the accelerated industry learning since tanks were mandated in 2008.
   - This review ought to lead to a stated benchmark of tank system designs that minimise maintenance requirements and maximise tank system reliability.
   - This should help system designers, installers and also householders to make more informed choices when selecting their systems.
2. Work with appropriate organisations and institutions on the appropriate amendment of design guidelines and/or standards, in light of the above review.

5.3. Promoting Good Installation

The installation of rainwater tanks has been suggested to be of variable quality. It is thought that the advent of mandatory certification for installation in new dwellings has improved the quality of installations compared to householder DIY retrofit installations. In Queensland, currently certification is carried by an accredited building certifier as rainwater installations are classified as structures; however any connections to water fixtures and connections to utility mains water supply need to be inspected by plumbers as they fall under the Plumbing Code. However, a number of plumbers have indicated that mistakes in installation are still observed in the field. There appears to be a need to review whether further training and education of professionals on the appropriate installation of rainwater tank systems should be standardised and included as part of the training. If this is the case, then a training program for plumbers on the appropriate installation of tanks needs to be developed. Installation of rainwater tank systems may become more consistent if dedicated training and education of professionals on installation of rainwater systems becomes more widespread. At present, specialised voluntary schemes such as the Green Plumbers (http://greenplumbers.com.au/) are available for training on sustainable practices. Furthermore, installation and certification of rainwater systems is covered under the Plumbing Code, and there are potential risks to water supply connections and stormwater drainage which in some instances are not properly addressed during inspection. As a result, installation warranty should be covered by the plumbers' liability, which will force plumbers to conduct correct installations. Under the Plumbing Code, certification would then have to be conducted either by council or by a certified plumbing inspector. In short, the recommendations for promoting good installation in the medium term are:

1. Review the need for providing better training for plumbers on the installation of tanks. If, as several professionals have noted, the need exists, then a program for training of plumbers needs to be developed and delivered.
2. Update the post-installation certification of tanks and expand it to include all components of the rainwater tank system including adequate connected roof area, pump sizing, etc. This means that it is covered under the Plumbing Code and the certification would need to be done by a trained and/or certified plumber. The details of how this change in the certification process would be done needs to be worked out by the industry and regulators but may include extending the scope of inspections to assess adequate roof area, mosquito meshing, drainage connections, etc.

5.4. Promoting Good Maintenance

From the perspective of water planners and health authorities, the two key goals of maintenance are:

1. Ensuring that water savings are maintained over time; and
2. Ensuring that rainwater tanks do not pose a health risk to the community, at any point in time.

The likelihood of these goals being realised is underpinned by tank owners undertaking or organising regular maintenance activities of their rainwater tank systems. This includes activities such as: regular checking and cleaning of the roof, gutters, and first flush device; checking and maintaining insect screening on tank inlets and outlets; checking and maintaining tank and pipe integrity; maintaining the pump in sound functioning order; checking and removing tank sediments; and monitoring water quality with regular checks of water colour and odour (Queensland Government, 2012a; 2012b).

Research to date suggests a variety of approaches that could be used to encourage tank maintenance activities. Possible approaches range from more coercive approaches, such as the use of regulation and penalties, through to less coercive approaches such as education and incentives (Walton *et al.*, 2012). The findings from the stakeholder workshop, focus groups, and a tank owner survey (Walton and Gardner, 2012) suggest that less coercive approaches are perceived as more acceptable by the community. Moreover, these types of approaches are judged as fairer, and more effective at encouraging tank maintenance, than more coercive approaches. The survey findings also indicated that tank owners' judgements of policy fairness and effectiveness influence their acceptance of the policy, and that fairness is twice as important as effectiveness in influencing policy acceptability (Walton and Gardner 2012).

These findings suggest that use of non-coercive or 'soft' approaches as ways of encouraging tank maintenance are most likely to be acceptable to tank owners. In general, such 'soft' approaches can take many forms including education, information, the use of incentives, feedback, and social marketing (House of Lords, 2011; Osbaldiston and Schott, 2012). Choosing which approach to use depends on the factors that influence or determine the behaviour that is targeted for change. In the context of encouraging tank maintenance behaviour, previous research has identified a number of factors that underpin a person's motivation and subsequent intention to undertake tank maintenance behaviour (Mankad *et al.*, 2011; 2012; Walton *et al*, 2012; Walton and Gardner, 2012). These factors can be grouped into four main areas: a positive attitude towards tank maintenance, based on the benefits of having a tank; possessing self-efficacy, the necessary skills, knowledge and control belief of being capable of undertaking tank maintenance; a sense of moral obligation that maintaining a tank is the 'right thing to do'; and a self-image of being someone who keeps things well maintained. In addition, survey research indicates the particular importance of self-efficacy in undertaking tank maintenance behaviour. Despite the best intention to keep the tank maintained, if a person is not capable of maintaining the tank, results suggest that tank maintenance will not occur (Walton and Gardner, 2012). Figure 5 illustrates the psychosocial factors underpinning an intention to maintain a rainwater tank; more detailed descriptions of these factors are provided in Appendix B.

Promoting tank maintenance could, therefore, be advanced using 'soft' approaches to address the four underlying factors associated with tank maintenance intention. First, positive attitudes towards tank maintenance could be fostered by increasing the awareness to tank owners of the personal benefits associated with maintaining a tank, and the possible costs of not maintaining the tank. The potential benefits could include the opportunity to save on mains water, to have the freedom to use tank water as they want, and to drought-proof themselves against future droughts. The costs of not maintaining the tank could include the wasted asset of the tank if the tank or pumps fail through lack of maintenance, and the wasted opportunity to capture water, otherwise going to waste. Social marketing techniques could be used to promote these types of attitudes (Andreasen, 2006; McKenzie-Mohr, 2011).

A second approach would be to address the tank owner's self-efficacy at being able to maintain a tank. This includes ensuring the tank owner has the necessary, knowledge, skills and capability to try and maintain their tank. Information and education, in conjunction with activities that create increased levels of awareness to undertake tank maintenance, could be useful. The use of dedicated websites that offer tailored information, 'how to maintain a tank' video, fact sheets, and a directory of service providers are examples that could assist tank owners in increasing their capability and access to tank maintenance services.

Appealing to a moral motive (i.e. being a good citizen, minimising public health risks and contributing to a common good) for undertaking tank maintenance could also be effective as a third approach to encourage tank maintenance. Appealing to the 'good citizen', that tank maintenance helps to prevent any mosquito related problems and helps to drought-proof the region by reducing mains water demand, could be ways to encourage tank maintenance in some people.

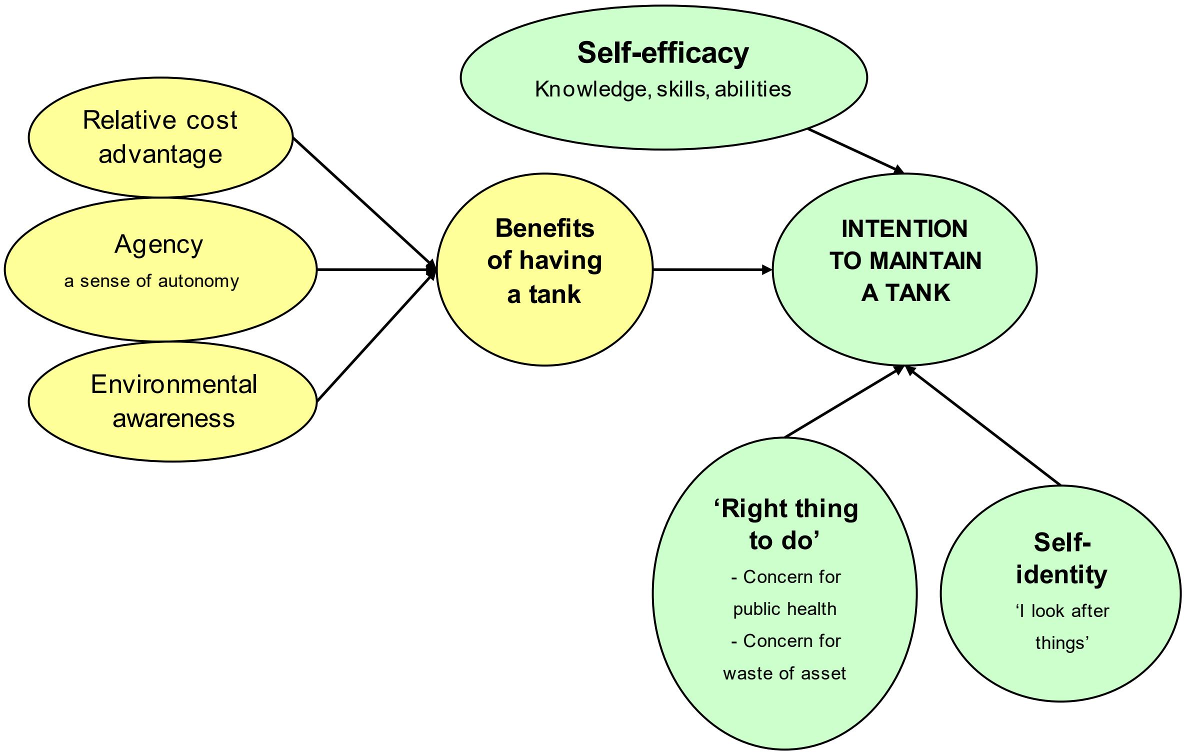


Figure 5: Socio-psychological model of the intention to maintain a rainwater tank.
Source: Walton et al., 2012.

A further approach to encourage tank maintenance could be to address tank owner expectations at the time of purchasing a tank, which, over time, contributes to creating new norms associated with owning a tank. It will be beneficial if a tank owner clearly understands tank ownership requirements and responsibilities right from the outset. This includes an awareness of tank maintenance and the possible maintenance and operation costs, as well as time commitments, so that the tank owner is informed up front and can organise tank maintenance with clear understanding of what is involved. This type of initial understanding could help alleviate potential issues of 'unfairness' that may be encountered later when trying to encourage tank maintenance behaviour.

A final approach could be to encourage tank maintenance as part of a schedule of normal house maintenance activities, such as regular pest control, to appeal to those that see themselves as someone who likes to keep things in 'good order'.

5.5. Recommended Action Strategy

The recommended strategy for improved rainwater tank management needs to be developed considering the following key aspects:

- The evidence is growing that there is a problem with ongoing maintenance of rainwater tanks in urban environments in Australia. This problem manifests itself in two ways that are important:
  - Rainwater tanks that are in poor condition pose a public health risk due to the risk related to contaminated water (the Government recommends that the public not drink untreated rainwater where a potable supply is available), but more importantly due to the risk of mosquito born disease as poorly maintained tanks can provide habitat for mosquitoes breeding.
  - Rainwater tanks that are in poor condition may provide only limited water savings. A pump that is broken or inoperable, blocked or has faulty plumbing will cause savings to be restricted. This may lead to underuse of huge community investment.
- The extent of the problem is, however, largely unknown, albeit there is some limited information from inspection programs. This creates serious concerns relating to the capacity for managing public health risks, and negates much of the value that rainwater tanks provide because water planners are unable to accurately estimate water savings, and this in turn may lead to planning for costly supply options.
- There are three key factors contributing to a tank system being in a good condition: design, installation and maintenance. There are concerns in all of these aspects, although the main concern seems to be maintenance. There are also strategies for addressing these three aspects, but the exact benefit of the strategies is difficult to quantify. Initial quantification of some of the effects is relatively negative in that it raises questions regarding the difficulty of making sure that public health risks can be adequately managed.
- An annual inspection program of tank conditions, based on random sampling, can be set up at a relatively low cost. Such a program ought to be the foundation for managing public health risks in an informed manner, and will allow water planners to quantify predictions of water savings into the future. Such a program can also help assess the effectiveness of any attempts at improving tank system conditions across SEQ.

These points show that there are a number of activities that can be undertaken in order to improve the management of rainwater tanks, and these are shown in Figure 6. The first steps for the most part relate to collecting information and better data management, as well as reviewing the need for legislative and other changes to the institutional framework.

Something that could be implemented in phase 1 at relatively low cost is the strategies to motivate, remind and enable owners by addressing the underlying factors that contribute to the intention to maintain the tank (see Figure 5). This would be done by providing information and developing the skills and ability of tank owners, as well as promoting the public and individual benefits of tank ownership.

In the second phase, there is a move towards action, including random inspections of tanks, changes to the design and installation guidelines and standards, and implementation of a training program for plumbers.

The third phase is to review the efficacy of the chosen strategies, and to evaluate what is working and what is not working. It will also be important at this stage to make a fair assessment of the public health risk, and to evaluate whether such risk can be managed or whether further actions would be required.

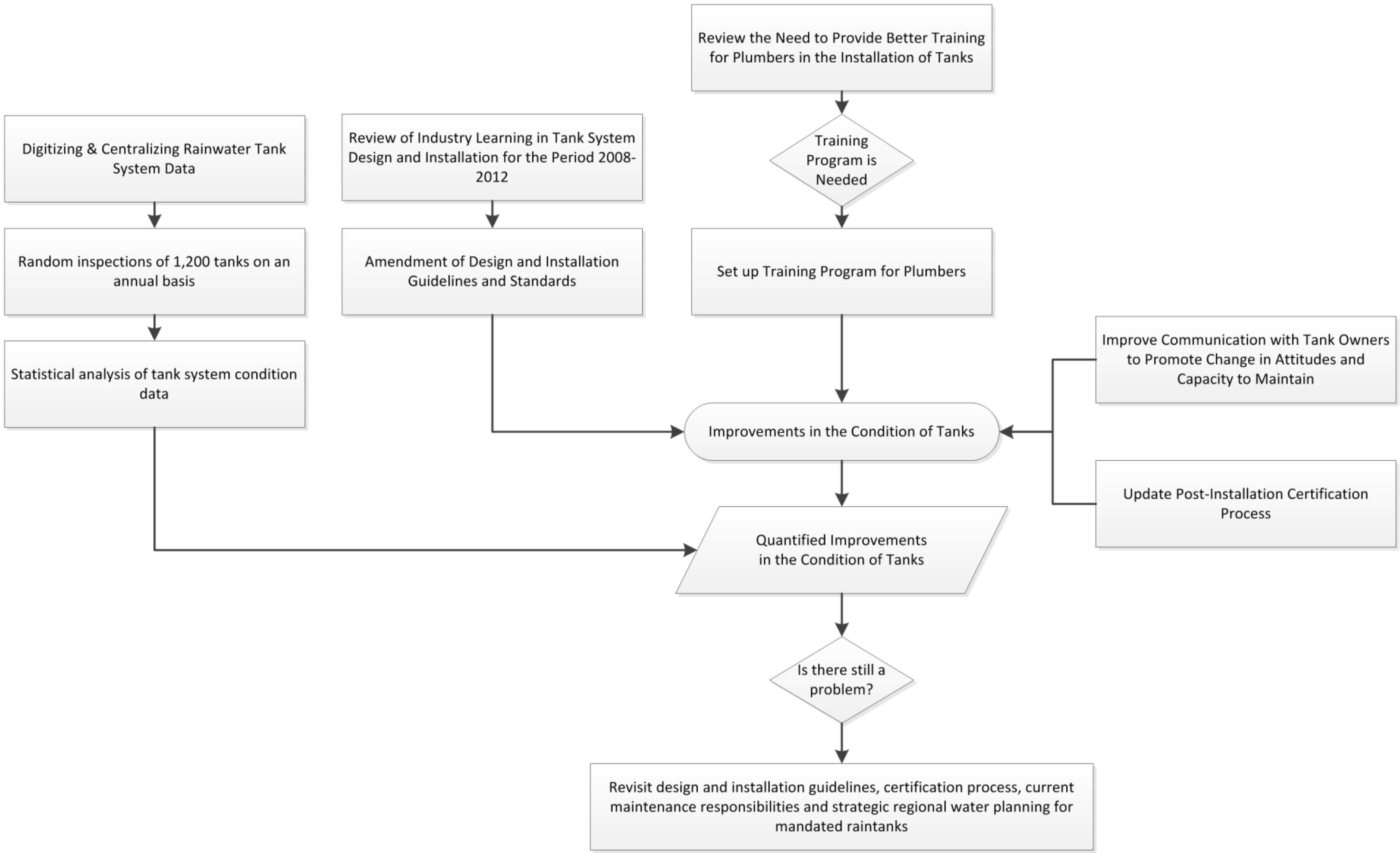


Figure 6: Staging of a rainwater tank management strategy.

6. CONCLUSIONS

Rainwater tanks were installed across Australia in response to the recent “dry run” that left many major cities struggling to maintain a positive supply-demand balance. Rainwater tanks were thought to provide good value in rural areas, and surely this technology could easily be applied in urban areas. It is a relatively simple technology that, when householders and owners take their responsibilities seriously, can be quite easily managed and can ease pressure on water supply.

In SEQ, rebates for the installation of rainwater tanks were made available by the State and local governments. Following the initial perceived success of the tank rebate schemes, the Queensland Development Code MP4.2 (Queensland Government, 2008) was amended to require all new single dwellings across Queensland built after January 2007 to have rainwater tanks and/or other non-mains water sources installed (such as greywater treatment plants, communal rainwater tanks, dual reticulation or treated stormwater) in order to meet specified mains water savings targets.

There are now over 300,000 tanks in the SEQ region, and if one assumes a cost per tank at a little over $3,000 including installation, this amounts to a community investment of approximately $1 billion. Regardless of what one may think of the wisdom of this investment, there are very good reasons for not letting this significant investment go to waste.

This report is the last in a series of reports from four interconnected studies, aiming to identify and evaluate appropriate action strategies to improve the management of rainwater tanks in the SEQ region.

The first part of this report overviewed the findings of the four previous studies. The initial investigation study identified a concern for O&M of rainwater tanks in SEQ, and that empirical data on the condition of domestic tank assets was minimal. However, such data is necessary to evaluate the effectiveness of various possible management strategies in the future. It was also found that very few government and industry stakeholders would like anyone other than householders to have the main responsibility for operation and maintenance of tanks. This position was supported by the findings from the stakeholder workshop and community focus groups. If householders remain responsible for tank maintenance, the findings from the previous research studies suggest that any governance arrangements need to be collaborative with householders through the use of non-regulatory approaches.

It is important to ensure that the investment in rainwater tanks is properly used to deliver desired outcomes in terms of mains water savings without posing any serious health risk. There is a growing body of evidence to indicate that the risks of such events need to be managed. This research highlights the need for a three-part approach involving good tank design, installation and maintenance. The research findings indicate that all three of these areas can be improved to deliver an outcome that supports satisfactory maintenance of rainwater tanks in the future.

As a possible way forward for stakeholders, this report has outlined a three-phased strategy for addressing the problem, in a way that starts to move towards an evidence base that can be used to inform policy.

The first phase of an action strategy revolves around gaining better understanding of and collecting information on rainwater tank systems. Data on the condition of tanks needs to be collected and managed centrally. Annual inspection programs need to be scheduled and coordinated. This first phase should also include a review of the adequacy of current design and installation guidelines. Communication with householders to inform and educate about the benefits of tanks as well as providing information to support them in their maintenance tasks is an essential element of the first phase of this strategy. A soft approach to engaging with householders is recommended, in which householders are supported and motivated to undertake maintenance rather than using penalties or rewards.

The second phase involves: changes to standards and guidelines identified in the phase one review; training of plumbers; updating of the post-installation certification processes; and analysis of the efficacy of all these actions as measured by the statistical improvement of the condition of tanks.

The third phase involves review of prior actions, evaluation of the associated health risks, and to revise actions or decisions as appropriate.

Throughout the three phases, targeted communication and information support for householders is recommended. We hope that all these actions taken together will help promote the efficient and safe use of rainwater tanks across SEQ into the future.

APPENDIX A: Description of Strategic Options for Management of Rainwater Tanks

Note: this list of options is an extract from Walton et al. 2012a. The list of options was developed in a workshop setting.

1. Self Management Strategies

The purpose of these types of strategies was to enable tank owners to independently undertake tank maintenance. Essentially, the tank owner would be responsible for maintaining the tank themselves, but with support provided by government to facilitate and enable tank maintenance. Ideas for this support included:

- Communication campaigns; promoting benefits associated with maintaining a tank, and highlighting consequences of not maintaining a tank;
- Creating awareness within the community of the need for undertaking maintenance tasks;
- Providing prompts to perform various tank maintenance tasks;
- Promoting tank maintenance as part of routine house maintenance;
- Information regarding a maintenance schedule (tailored to the tank owner's situation);
- Web-based interactive resources;
- General fact sheets and information to encourage 'Do it yourself' maintenance;
- Telephone help lines; and
- Directories of services.

It was recognised that providing information alone would not necessarily result in improved motivation to undertake tank maintenance behaviour. A communication strategy was considered a necessary element to encourage and empower tank owners to assume responsibility for maintaining their tank. Tanks owners were also recognised as being a disparate group with varying motivations, capabilities and attitudes.

2. Home-Based Service

This type of strategy was modelled on the current 'Climate Smart' program, with the aim of providing an inspection service requiring a small co-payment from the tank owner. This program would be subsidised by government. There were divergent opinions about the extent of the services that should be provided, ranging from an inspection and advice type of service, through to a hands-on maintenance service.

3. Changes to Regulations and Codes to Improve Design and Installation

The rationale behind these strategies was that prevention of problems can be influenced significantly by tank design and installation. It was suggested by some participants that some rainwater collection systems are not well designed, and that some tanks are not correctly installed, although to date there is no strong evidence about the extent of these problems. By ensuring a tank is "maintenance-proofed" at the outset, future maintenance needs are minimised. Similarly, ensuring the tank is properly installed would further diminish future problems. Enforced inspections of installations by plumbers were considered integral to these strategies. Amendments to various regulatory instruments would be required to support the strategy. For example:

- Changes to or replacement of QDC 4.2 changes to address design and installation issues; and
- Amendment to the Plumbing and Drainage Act 2002 and the Standard Plumbing and Drainage Regulation 2003.

4. Create a Register of Tanks

The purpose of these strategies was to create a register of tanks that would provide information on tank assets within the region. This in turn would support a program of random checks on household tank conditions as an instrument to support adaptive governance (i.e. evaluating whether current policies work). Local council was deemed as the suitable entity for maintaining a tank register. Various suggestions for how a tank register might be created included:

A. Compulsory registration, modelled on swimming pool registration.

B. Registration and certification linked to installation, and subsequent plumber's inspection at time of installation.

5. Regulate Ongoing Maintenance

The purpose of regulation was to ensure the ongoing maintenance of the tank through regular inspections and associated penalties. The current swimming pool model of regulation was suggested as a framework for management. Participants recognised that applying regulation to tank maintenance was likely to be difficult, expensive, de-motivating and potentially interpreted by tank owners as over-regulation (an example of the "nanny state"). However, the idea of incorporating tank inspections into pre-sale building inspections, along with pest inspections, was considered favourably.

APPENDIX B: Description of Important Socio-Psychological Factors

Note: this is an extract from Walton et al. 2012a, to describe important factors contributing to the intention to undertake maintenance of a tank.

Analysis revealed seven factors that were important to tank owners in relation to undertaking prevention behaviours and accepting policy interventions for fostering such behaviour. The groups of factors included: the relative cost-benefit of undertaking the behaviour, issues of agency, awareness of the environment, efficacy, moral norms, self-identity and a lack of a perceived need for any intervention. Each of the factors is discussed below.

1. Relative Cost-Benefit

For many people, the potential advantage of saving money on water costs was an important motivating factor for maintaining a tank, and any erosion of this benefit would consequently act to demotivate the tank owner. Cost savings appeared to play a significant role in attitude formation and for many it was fundamental to the original purchase decision. However, tank owners reported that the costs actually saved from having a tank were probably marginal. Even though research suggests tanks contribute to water savings of up to one third for an average size dwelling (Chong *et al.*, 2011), this does not seem to translate to a proportionate savings in costs. In part, this is due to the format of the utility bill, in which only a small portion reflects the variable cost related to water usage. The remaining parts of the bill reflect fixed costs passed on to the consumer as infrastructure charges. As a consequence, most participants only reported minor reductions in the water bill, despite reductions in water use likely to be more significant.

Therefore, participants assessed any potential strategies that incurred significant costs as unattractive, because of the likelihood to erode any cost advantage. Even interventions such as registers and inspections implied that there would be some sort of ensuing cost, for example, a licence fee to register or an inspection fee with any inspection process, and that this cost would be additional to any actual maintenance costs. This presumed cost would reduce the financial benefit as a motivation, and likely result in people reconsidering using their tank, especially if things began to malfunction. Reinforcing this perspective were the reports by some participants who had already experienced repair costs related to pump failure, that they were considering reverting to mains water because the cost of repair outweighed the savings gained.

2. Agency Issues

The ability to act autonomously, and be an agent of one's own decisions, appeared to be a major influence on participants' attitudes and views regarding tank maintenance behaviour and possible policy interventions. For many the idea of having freedom to 'do what I want with my water' was a significant motivation for getting a tank in the first place. This notion seemed to extend to attitudes related to managing the tank. The idea that an intervention might try to 'enforce' tank maintenance was viewed very negatively, as this seemed to work against the concept of agency.

The literature describes agency, according to the economist Sen, as 'the ability to define one's goals in an autonomous fashion and act upon them.' (Pick, 2007, p.234), and is akin to concepts of autonomy and self-determination. The importance of agency is highlighted by public concerns about 'the nanny state', where citizens react negatively to overly paternalistic policy approaches by government. Research has suggested that public perceptions of unfairness, infringement of freedom, and perceptions of coercion have been associated with lower levels of policy acceptance (Cherry, Kallbekken and Kroll, 2011; Ericksson, Garvill and Nordlund, 2006; Fujii, Garling, Jakobsson and Jou, 2004). In this present study, some participants indicated they would engage in counter-productive behaviour, such as abandoning their tank, if there were attempts at introducing regulatory approaches as a way of encouraging tank maintenance.

Rather, participants reported they wanted choices and options for managing tank maintenance. For some the preferred option was self-management, for others it was access to a home-based service, or information and web-based resources. Participants also supported interventions that did not directly affect them. For example, they were very supportive of any improvements to tank design and installation, and saw these types of interventions as very effective and acceptable, even if these changes resulted in additional cost to the initial outlay of the tank. It was also seen as important that a tank owner should be able to know up front what the expectations were surrounding owning a tank. Full disclosure of costs involved with maintaining a tank would enable people to make informed decisions, and create awareness of the care and responsibility of owning a tank.

3. Awareness of the Environment

An awareness that a tank could contribute to safe guarding against a potential shortage of water was a perceived benefit to all groups of participants. Participants were positive about the idea of having a tank as a way of securing additional water during periods of a drought. Although the region was currently experiencing an abundance of water, participants felt that droughts were cyclical events and likely to return. There was suggestion that if this were the case, their motivation levels for having the tank and maintaining it would be increased. This type of view is in line with previous research which has demonstrated that a perceived threat, such as in a drought, is a motivator for adopting a tank or other decentralised water systems (Mankad, Tapsuwan, Greenhill, Tucker and Malkin, 2010).

4. Efficacy

The feeling of being capable of maintaining a tank was a major issue for all participants. Capability in terms of knowledge, skills and abilities were all important factors. Participants suggested efficacy could be improved through: increased awareness, knowledge of the activities involved, provision of 'how to do it' facts, and information on how to access relevant service providers. Thus, participants viewed any interventions that supported improvement in efficacy as both acceptable and effective. Conversely, interventions that didn't improve efficacy were judged negatively. For example, participants did not see how creating tank registers, or forms of mandatory inspections, would assist in getting a tank maintained.

Efficacy is a concept widely recognised in social science for its importance in achieving behaviour change. A person's belief that he or she has the necessary skills and abilities to undertake the target behaviour, and the control over any environmental constraints is a powerful variable in fostering behavioural change (Armitage and Conner, 2001; Azjen, 1991; Olander and Thogersen, 1995).

Participants also indicated that being provided with information alone would not be very effective. Rather, information needed to be used in tandem with other motivation strategies such as creating awareness and highlighting the benefits of keeping a tank well maintained. This view was supported by those participants who reported being provided with a maintenance information brochure at the time of installation, but never having bothered to look at it again, unaware of the value of keeping their tank maintained.

A final factor impacting efficacy was a busy lifestyle. Many participants felt that their lives were full, and their resources for attending to additional tasks were limited. The need to expend time, attention and care on activities for maintaining the tank would be viewed as difficult, especially if the burden increased to include inspections and registration. If however, some of these tasks could be included in other routine 'house maintenance' tasks, it would not only improve the likelihood of getting it done, but also be more acceptable. For example, if tank maintenance could be included in pest control, or swimming pool inspections, this would ultimately improve efficacy for tank maintenance behaviour.

5. Moral Norm

For some participants there was a sense of feeling obliged to look after their tank; that it was 'the right thing to do'. This sense of moral obligation seemed to be based on two main reasons; not wanting to waste the financial resources invested in the tank (both at a personal level and at a public investment level); and not wanting to create a potential public health risk. If equipped with suitable capability, these individuals felt they would be motivated to keep their tank maintained. A sense of moral obligation, or personal norm, has been described in the literature as a powerful motivator of pro-social behaviour, particularly in the environmental field (Harland, Staats, and Wilke, 1999; Spinks, Fielding, Russell, Mankad, and Price, 2011; Stern, 2000).

6. Self-Identity

Some people saw themselves as 'someone who keeps things maintained and in good repair'. These individuals viewed maintaining a tank as no different from keeping the air conditioner regularly serviced, or the carpets annually cleaned, and indicated if they knew what and when things were to be done they would do so. Furthermore, some saw themselves as a 'do it yourself' type of person and suggested all that they needed to know was what was required and that they would keep their tank maintained. This suggests if efficacy levels were improved this type of person would be motivated to keep the tank maintained. Self-identity has been an important predictor of behaviour across many domains including the environmental field (Sparks and Shepherd 1992; Terry, Hogg, and White, 1999; Whitmarsh and O'Neill, 2010).

7. No Perceived Need for Regulatory Intervention, Beyond Risks to Public Health

Participants indicated the level and type of intervention for encouraging tank maintenance needed to reflect the level of need for the intervention. Because many participants were 'only' using their tank water for external garden use, they found it hard to understand that this type of use warranted any interventions that were viewed as too 'heavy handed'. On the other hand, if the tank water was used for drinking then they could understand the need for more regulatory interventions. Along this same theme was the recognition by participants that if a situation arose related to a public health risk, such as increased prevalence of mosquito-borne illnesses, then they would be more amenable to regulations, including registers and inspections to manage this type of situation.

Therefore, participants seemed unconvinced as to the need for an intervention response beyond self-management approaches, and viewed any alternate intervention with suspicion. In particular, tank registers were viewed very negatively, not only because tank registers were not perceived to assist the tank owner in maintaining a tank, but also because participants felt that government should already have this type of information. Participants felt that data related to rebate schemes and new home builds would already exist, and therefore, they did not understand the need for having a register.

APPENDIX C: Bayesian Network Probability Tables

This appendix contains what is referred to as Conditional Probability Tables (CPTs). For example Table 15 shows the likelihoods of different levels of maintenance (shown in different columns), for three different scenarios (shown in different rows). All values in the table are probabilities.

Table 15: Probability table. Likelihood of adequate maintenance as per professional survey.

	Yes (%)	Patchy (%)	No (%)
Best case (N/A group)	65%	17.5%	17.5%
Worst case (Govt)	20%	40%	40%
Average case (all)	52%	24%	24%

Table 16 similarly shows different quality of design of installation (rows), calibrated using two different data sets (one star or two stars below).

Table 16: Probability table. Problems in design or installation.

	Benchmark (%)	Ok (%)	Poor (%)
Design*	6	75	19
Installation*	7	75	18
Design**	12	82	6
Installation**	14	80	6

***Note**: estimated on the basis of plumbers survey results.
****Note**: estimated on the basis of plumbers' survey results but adjusted to take into account that plumbers only see the bad cases. The adjustment has been done considering that tanks plumbers don't see are likely to be approximately three times fewer problems than the tanks that they see.

Table 17 shows the level of water savings (columns) for different conditions (rows) relating to whether tanks are in good condition and whether they are mandated or rebated tanks.

Table 17: CPT. Water Savings - Condition.

		Full Savings (%)	Some Savings (%)	No Savings (%)
Rebated	Good condition	95	5	0
Rebated	Poor condition	24	30	46
Mandated	Good condition	95	5	0
Mandated	Poor condition	21	33	46

Note: These numbers are reported rates of problems with pumps and /or piping by plumbers in the plumbers' survey. It is based on their reported rates of problems.

Table 18 shows the likelihood of mosquito problems in tanks (columns), in different circumstances relating to whether the tank is in a good condition and whether it is rebated or mandated.

Table 18: CPT. Mosquito problems - Condition.

	Mosquitoes (%)	No Mosquitoes (%)
Good condition (Rebated)	1	99
Poor condition (Rebated)	36	64
Good condition (Mandated)	1	99
Poor condition (Mandated)	35	65

Note: These numbers are reported rates of problems with mosquitoes as reported by plumbers in the plumbers' survey and based on their reported rates of problems with mosquito meshing.

Table 19 shows the likelihood of sampling style, in different scenarios relating to the adequacy of the knowledge of the tank stock, and the type of sampling programs being undertaken.

Table 19: CPT. Knowledge of condition - Knowledge of stock and Sampling of tanks.

Knowledge of Tank Stock	Sampling of Tanks	Almost All Tanks Sampled (%)	Anecdotal (%)	Random Sample (%)
Benchmark	All	100	0	0
Benchmark	Random	0	0	100
Benchmark	Too small	0	95	5
Some	All	0	20	80
Some	Random	0	50	50
Some	Too small	0	95	5
Poor	All	0	90	10
Poor	Random	0	95	5
Poor	Too small	0	99	1

Table 20 shows the likelihood of householders' undertaking maintenance (columns), depending on their intention to maintain the tank (rows).

Table 20: CPT. Householder maintenance - Householder intention.

Householder Intention	Yes (%)	Patchy (%)	No (%)
Yes	80	15	5
Undecided	30	35	35
No	20	30	50

Source: The conditional probabilities in this table have been calibrated in order to achieve levels of maintenances as reported in the professional survey (average judgments).

Table 21 shows the likelihood of a householder intending to maintain their tank (columns) in a range of different scenarios relating to the underlying socio-psychological factors (rows).

Table 21: CPT. Intention to maintain - Socio-psychological factors.

Perceived Benefits	Efficacy	Right Thing To Do	Self Identity	Yes (%)	No (%)	Undecided (%)
Yes	Yes	Yes	Yes	70	10	20
Yes	Yes	Yes	Undecided	68	12	20
Yes	Yes	Yes	No	66	14	20
Yes	Yes	Undecided	Yes	63	17	20
Yes	Yes	Undecided	Undecided	61	19	20
Yes	Yes	Undecided	No	59	21	20
Yes	Yes	No	Yes	56	24	20
Yes	Yes	No	Undecided	54	26	20
Yes	Yes	No	No	52	28	20
Yes	Undecided	Yes	Yes	55	25	20
Yes	Undecided	Yes	Undecided	53	27	20
Yes	Undecided	Yes	No	51	29	20
Yes	Undecided	Undecided	Yes	48	32	20
Yes	Undecided	Undecided	Undecided	46	34	20
Yes	Undecided	Undecided	No	44	36	20
Yes	Undecided	No	Yes	41	39	20
Yes	Undecided	No	Undecided	39	41	20
Yes	Undecided	No	No	37	43	20
Yes	No	Yes	Yes	41	39	20
Yes	No	Yes	Undecided	39	41	20
Yes	No	Yes	No	37	43	20
Yes	No	Undecided	Yes	34	46	20
Yes	No	Undecided	Undecided	32	48	20
Yes	No	Undecided	No	30	50	20
Yes	No	No	Yes	27	53	20
Yes	No	No	Undecided	25	55	20
Yes	No	No	No	23	57	20
Undecided	Yes	Yes	Yes	60	20	20
Undecided	Yes	Yes	Undecided	58	22	20
Undecided	Yes	Yes	No	56	24	20
Undecided	Yes	Undecided	Yes	53	27	20
Undecided	Yes	Undecided	Undecided	51	29	20
Undecided	Yes	Undecided	No	49	31	20
Undecided	Yes	No	Yes	46	34	20
Undecided	Yes	No	Undecided	44	36	20
Undecided	Yes	No	No	42	38	20
Undecided	Undecided	Yes	Yes	45	35	20
Undecided	Undecided	Yes	Undecided	43	37	20
Undecided	Undecided	Yes	No	41	39	20

Perceived Benefits	Efficacy	Right Thing To Do	Self Identity	Yes (%)	No (%)	Undecided (%)
Undecided	Undecided	Undecided	Yes	38	42	20
Undecided	Undecided	Undecided	Undecided	36	44	20
Undecided	Undecided	Undecided	No	34	46	20
Undecided	Undecided	No	Yes	31	49	20
Undecided	Undecided	No	Undecided	29	51	20
Undecided	Undecided	No	No	27	53	20
Undecided	No	Yes	Yes	31	49	20
Undecided	No	Yes	Undecided	29	51	20
Undecided	No	Yes	No	27	53	20
Undecided	No	Undecided	Yes	24	56	20
Undecided	No	Undecided	Undecided	22	58	20
Undecided	No	Undecided	No	20	60	20
Undecided	No	No	Yes	17	63	20
Undecided	No	No	Undecided	15	65	20
Undecided	No	No	No	13	67	20
No	Yes	Yes	Yes	51	29	20
No	Yes	Yes	Undecided	49	31	20
No	Yes	Yes	No	47	33	20
No	Yes	Undecided	Yes	44	36	20
No	Yes	Undecided	Undecided	42	38	20
No	Yes	Undecided	No	40	40	20
No	Yes	No	Yes	37	43	20
No	Yes	No	Undecided	35	45	20
No	Yes	No	No	33	47	20
No	Undecided	Yes	Yes	36	44	20
No	Undecided	Yes	Undecided	34	46	20
No	Undecided	Yes	No	32	48	20
No	Undecided	Undecided	Yes	29	51	20
No	Undecided	Undecided	Undecided	27	53	20
No	Undecided	Undecided	No	25	55	20
No	Undecided	No	Yes	22	58	20
No	Undecided	No	Undecided	20	60	20
No	Undecided	No	No	18	62	20
No	No	Yes	Yes	22	58	20
No	No	Yes	Undecided	20	60	20
No	No	Yes	No	18	62	20
No	No	Undecided	Yes	15	65	20
No	No	Undecided	Undecided	13	67	20
No	No	Undecided	No	11	69	20
No	No	No	Yes	8	72	20
No	No	No	Undecided	8	74	20
No	No	No	No	4	76	20

Table 22 shows the likelihood of tank condition (columns), depending on the underlying adequacy of design, installation and maintenance (rows).

Table 22: CPT. Condition of tanks - maintenance, design and installation.

Maintenance	Design	Installation	Good	Poor
Yes	Benchmark	Benchmark	100%	0%
Yes	Benchmark	Ok	100%	0%
Yes	Benchmark	Poor	88%	13%
Yes	Ok	Benchmark	100%	0%
Yes	Ok	Ok	100%	0%
Yes	Ok	Poor	88%	13%
Yes	Poor	Benchmark	88%	13%
Yes	Poor	Poor	75%	25%
Yes	Poor	Ok	88%	13%
Patchy	Benchmark	Benchmark	80%	20%
Patchy	Benchmark	Ok	80%	20%
Patchy	Benchmark	Poor	68%	33%
Patchy	Ok	Benchmark	80%	20%
Patchy	Ok	Ok	80%	20%
Patchy	Ok	Poor	68%	33%
Patchy	Poor	Benchmark	63%	38%
Patchy	Poor	Poor	55%	45%
Patchy	Poor	Ok	68%	33%
No	Benchmark	Benchmark	60%	40%
No	Benchmark	Ok	60%	40%
No	Benchmark	Poor	48%	53%
No	Ok	Benchmark	55%	45%
No	Ok	Ok	60%	40%
No	Ok	Poor	48%	53%
No	Poor	Benchmark	48%	53%
No	Poor	Poor	35%	65%
No	Poor	Ok	48%	53%

Note: this table has been set up on the basis of ratio of importance of maintenance over design and installation being 3:1 (on the basis of professionals' survey). Spreadsheet set up to make numbers consistent, and calibrated to achieve rates of tanks in good condition, as observed in alternative rainwater tank surveys (Biermann *et al.* 2012; Umapathi *et al.* 2012).

Table 23 shows the estimated prevalence of various socio-psychological factors in the population; as they relate to the intention to maintain a rainwater tank.

Table 23: Probability distribution of socio-psychological factors.

Socio-Psychological Factor	Yes	Undecided	No
Perceived benefits (attitude)	55.7%	39.2%	5.1%
Right thing to do	35.1%	42.2%	22.7%
Efficacy	54.6%	35.5%	9.9%
Self identity	65.5%	31.9%	2.6%

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