Mandatory urban rainwater harvesting: learning from experience

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ABSTRACT

Rainwater harvesting is effectively mandated in several urban areas of New Zealand. To understand the costs and benefits of rainwater harvesting from an end-user perspective, semistructured interviews were conducted with 14 homeowners in northern Auckland affected by these regulations. Residents report differences in four aspects of urban rainwater infrastructure – security of supply, water quality, the learning process and financial costs – that could represent key values for public acceptance. When responses are examined from the perspective of experience that has built empirical knowledge, participants explained how their satisfaction with rainwater harvesting increased over time. We hypothesise that for those lacking experience, urban rainwater consumption is a function of empirical knowledge and has initially rising marginal utility. Regulation that recognises the costs of social learning is likely to be a more effective pathway towards maximising the social benefits associated with integrated urban water management.

Key words | economics, integrated water management, policy, rainwater harvesting, regulation, sustainable infrastructure

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INTRODUCTION

To mitigate the detrimental environmental effects of urban stormwater runoff, local government in New Zealand is experimenting with residential development regulations that effectively mandate private rainwater harvesting at the private lot scale. Lawton *et al.* (2008) summarise the history of water resource regulation in New Zealand, and present domestic and international case studies in which rainwater tanks are effectively mandated through stormwater or water demand management policies in new peri-urban developments. Relevant regulation that governs land use in the northern suburbs of Auckland, where this research project interviewed residents, includes Plan Change 22 (North Shore City Council 2010) and Plan Change 6 (Variation 66; North Shore City Council 2006) to the North Shore City District Plan. These regulations require 'the installation of various on-site stormwater management devices to mitigate the adverse effects of stormwater runoff from new development on the environment' (North Shore City Council 2010, p. 1). In the current market, new urban development in New Zealand rarely considers rainwater harvesting without regulation or subsidy.

It is often argued that stand-alone centralised water supply and drainage systems, where water resources are managed at a single location, distributed to customers and then removed as quickly as possible, are inefficient as they do not take full advantage of urban stormwater resources (Coombes *et al.* 2002; Faram *et al.* 2010). Furthermore, in urban areas with high impervious surfaces and centralised stormwater drainage infrastructure, rainwater quickly turns from a valuable resource into a societal cost in the form of flooding, stream erosion, aquatic habitat destruction, and toxic loadings on receiving environments. Environmental, economic and social costs associated with centralised approaches to urban water management are exacerbated by common issues of population growth, climatic change, increases in per-capita water use, allocations for environmental flows, urban sprawl, etc. (e.g. Gleick 2003; Jenerette & Larsen 2006; Brown *et al.* 2009). Gleick (2003) suggests meeting future urban freshwater management demands will require a fundamental shift in technology and behavior.

Existing literature on urban rainwater harvesting has largely focused on quantifying the benefits and costs in a developed-country context. Specifically, research has been

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concerned with benefits and costs related to water quality and water quantity management outcomes from a water supply perspective (see Meera & Mansoor 2006; Hurlimann *et al.* 2009; Kettle 2009). If rainwater harvesting is perceived exclusively as a substitute technology for conventional freshwater management, its potential to promote sustainable behaviours and attitudes is diminished.

There has been little research into socio-cultural changes associated with rainwater harvesting. Hurlimann *et al.* (2009) reviewed a wide range of literature associated with social acceptance of general water management regimes and found a predominance of stated preference methodologies, leading to a knowledge gap of actual behaviours. Domènech & Saurí (2011) interviewed residents with rainwater harvesting in Barcelona, documenting differences in social knowledge accumulation between single-family and multi-family residential properties. A broad survey of UK residents by Ward *et al.* (2008) found most respondents had limited experience with rainwater harvesting, but stated positive preferences toward rainwater harvesting at an individual-property scale and underestimated maintenance requirements.

In theoretical discourse, the financial and environmental efficiency of rainwater harvesting continues to be debated. In most urban areas, rainwater tanks serve as a complement to existing water supply and stormwater management networks, rather than a substitute. This duplication results in higher life-cycle costs, greenhouse gas emissions and energy demand relative to having a rainwater supply only (Mithraratne & Vale 2007; Rabbitts 2009). Complexity associated with the incidence of costs and benefits for conventional water management infrastructure – commonly a mix of public and private investment (including many sunk costs) – makes it difficult to perform a societal cost–benefit analysis for rainwater harvesting infrastructure. Initial attempts (e.g. Rabbitts 2009) only account for water supply implications, despite the stormwater management rationale for rainwater harvesting regulations in New Zealand. International analyses have concluded that sunk costs are of such significance that conventional urban development has restricted choices available to future generations (Faram *et al.* 2010).

Another perspective is that integrated water management (which includes rainwater harvesting) is economically efficient from a societal viewpoint because of non-market values (externalities) and an inefficient distribution of costs and benefits (Vesely *et al.* 2005; Kettle 2009; Wilson *et al.* 2010). Non-market benefits associated with investment in integrated water management infrastructure, such as innovation, adaptation capacity and skill development, are not manifest in the rote provision of centralised pipe systems. Furthermore, the societal costs of ecological damage (present and future) are not included in municipal water prices, which are based on the costs of abstraction, treatment and distribution. These costs are either paid by society through public expenditure or passed on to future generations.

One potential solution is that non-market values associated with low-impact development – particularly the benefits associated with innovation and knowledge development – may be recognised by the market after implementation. Gabe *et al.* (2007) surveyed and interviewed users of a low-impact building that includes passive space conditioning and integrated water management, finding that satisfaction with these more unique features increased over three years. When applied to conventional economic theory, these non-market benefits may indicate a brief period of rising marginal utility for low-impact technology as the 'consumption' of social knowledge and user experience increases. Economists use the concept of marginal utility – the amount of satisfaction one receives by consuming an additional unit – to describe the principle of diminishing returns, which states that marginal utility declines as consumption of a particular good increases (satisfaction gained from the first unit consumed is greater than the second unit consumed). There are numerous exceptions to this principle, including activities that require training and experience (such as specialist consulting; Evers & Menkhoff 2004), but conventional economics assumes diminishing returns over the relevant range of consumption choices (Krugman & Wells 2009, p. 252). In the case of rising marginal utility, regulation can be an effective method for increasing societal well-being.

Given the knowledge gap of actual behaviours associated with rainwater harvesting, this paper examines the user experience with residential rainwater tanks to explore the values that urban end-users place on them, particularly non-market values. The authors originally intended to use hedonic regression to establish the revealed preference value of domestic rainwater harvesting. Hedonic regression (Rosen 1974) can be used to build a statistical model that controls differing characteristics of residential property (age, size, location, etc.) to establish the influence of rainwater tanks on house prices (all else being equal). However, the current number of rainwater-supplied house sales in a single New Zealand market was too low to establish a statistical significance. Consequently, this study uses a qualitative method to capture the breadth of potential causal

relationships in trends that may arise from future quantitative studies.

METHODS

The study concentrates on a peri-urban area in the northern suburbs of Auckland, where developers are converting pastoral land into low- and medium-density residential uses. Residents in the northern suburbs are statistically wealthier than other regions of Auckland and also highly educated, with 47.1% of the population having a post-secondary school qualification (Statistics New Zealand 2007). Domestic water consumption in the region averages 179 L/person/day, which is similar to the Auckland-wide average (Lawton 2008).

In this region, 2,352 households applied for a permit to install a rainwater tank prior to June 2009. Most, but not all, have been specified as a result of planning regulations on stormwater management for new construction (North Shore City Council 2006, 2010). From a random sample of this population, 14 residents of individual homes agreed to participate in a semi-structured interview on their experiences with urban rainwater harvesting.

Interviews were conducted to understand the perceived costs and benefits of rainwater harvesting infrastructure. Participants were encouraged to discuss specific anecdotes and thoughts that influenced their behaviour. The research aimed to document the discourse associated with rainwater harvesting, particularly the discourse that could influence market perceptions of value. It does not attempt to survey the frequency that particular opinions occur, nor fully document the financial costs and benefits of rainwater tanks beyond the perspective of the participants. Readers interested in a more comprehensive examination of financial costs and benefits associated with rainwater harvesting in New Zealand are encouraged to consult Mithraratne & Vale (2007) and Rabbitts (2009).

All 14 participants installed rainwater tanks as a direct result of regulation and all were owner-occupiers. There were six sole-supply systems (rainwater supply only) and eight dual-supply systems (rainwater and city supply). In dual-supply systems, rainwater was commonly used in toilets, outdoor irrigation, and laundry supply. City water serviced all other fixtures (kitchen, bathroom taps, shower, and hot water) and provided a backup for rainwater end-uses in the event of an empty tank. Sole-supply households consume rainwater for all end-uses (city supply is not piped into the house). In the event of a dry tank, sole-supply users have the option to buy city water top-ups delivered by truck. Rainwater tanks appeared to be sized to their end-uses where most dual supply tanks were 3–5 m^3, while sole-supply systems had between 22 and 40 m^3 of storage (though many residents expressed uncertainty towards the appropriate size of a rainwater tank).

Experience with rainwater harvesting infrastructure was highly variable; in one case, the resident was not aware his property had a rainwater tank until after occupying the property, while another resident had never used city water in her lifetime. The median time of participant experience with rainwater harvesting was 2 years.

RESULTS AND DISCUSSION

A number of subjective costs and benefits were identified by the interviewees (Table 1). The context of each cost and benefit is briefly discussed.

Costs

Net financial cost

Residents – particularly those using dual-supply systems – identified a range of expenditures that, in their perception, led to an increase in the financial cost of water supply management. Capital and maintenance expenditures featured prominently, with one resident that has lived with dual-supply for 4.5 years commenting, 'The tank itself cost NZ$4,500 to put in. And that was pretty annoying. And I probably save myself NZ$30–40 every 6 months on my water bill. But then I have to pay for the pump's electricity. So really what I'm saving in water, I'm not saving, because I'm paying the cost for running the pump. So I'm not really saving anything financially'.

Table 1 | Breadth of costs and benefits associated with rainwater harvesting in Auckland

Costs of owning a rainwater tank	Benefits of owning a rainwater tank
Net financial cost	Net financial benefit
Inefficient use of space (opportunity cost)	Control and freedom of use
Time costs	Intergenerational advantage
Energy consumption	Enhanced personal values
Behaviour changes	Insurance
Water quality	Water quality
Learning process	Learning process

Very few residents performed regular maintenance beyond visual inspections, so maintenance costs were often mentioned by owners who had experienced failures, such as a broken pump or leaking pipe. These residents sought advice and paid for repairs from 'expert' tradesmen or engineers. When cleaning became necessary – usually in response to poor water quality at the end-use – the job was outsourced to a specialist cleaning firm. Cleaning was thus perceived as a financial, not time, cost.

Some residents perceived net financial costs were high because local government was not considering the costs of their regulations. Many compared the water efficiency objectives of governments with residential energy efficiency objectives and expressed a desire for government rainwater tank subsidies in a similar fashion to the frequently advertised subsidies for home insulation.

Water rates (taxes) also influenced perceptions of net financial cost. Dual-supply residents did not receive discounts on their water rates, despite having a rainwater tank to reduce the burden placed on public infrastructure. On the other hand, sole-supply residents expressed satisfaction at being exempt from water rates.

Inefficient use of space

Most residents installed above-ground rainwater tanks, and some described them as an inefficient use of land. One resident on dual-supply explained how reducing the size of the tank was the main driver in his decision to implement rainwater harvesting in lieu of a larger stormwater retention tank: 'I was trying to reduce the size of it and [the regulatory agency] said, "Well, if you want it to be smaller you need to have a facility where you retain the water and pump it through your toilet systems and hose taps and the like." So I did that and reduced it down to 5,000 L'. Another owner described an opportunity cost of reduced vehicle parking.

Time cost

Time spent inspecting rainwater tanks was cited as the most common regular maintenance activity. Residents on sole-supply commented that the need to manage water supply in dry summer months led them to take time and regularly inspect the water level in the tank. Inspecting operability following the repair of a system failure was another demand on residents' time, particularly with dual-supply owners that experienced a failure in an automated system that fills the rainwater tank with city supply in dry periods. An extreme example of this was one dual-supply resident who removed an automated system that had failed and began manually topping up the rainwater tank with city supply from a hose and visually inspecting the water level on a regular basis.

Energy consumption

As the resident quoted earlier in regards to net financial costs attests, some residents on dual-supply felt that monetary savings from water supply efficiency were offset by energy costs. Another group of residents discussed how rainwater tanks increased their reliance on continuous electricity supply. One sole-supply resident comments: 'The only negative is the electricity. When there's a power cut we don't have water in the house … We can't flush toilets, and we have to get a bucket. It's a hassle but it doesn't happen very often-at least once a year'.

Behaviour change

Some residents evaluate their water consumption behaviour as a function of rainwater abundance, particularly in the summer months, when Auckland rainfalls are lower than average and demand can be higher due to irrigation. Contrary to Rabbitts (2009), who assumes no behaviour change when switching from town supply to rainwater supply, most residents on sole-supply describe how they are water-conscious by reducing water consumption during dry periods. Self-imposed restrictions, such as washing laundry on rainy days, as one resident reported, can thus be seen as a cost of rainwater harvesting.

Water quality

Poor water quality was seen as a deterrent to the use of rainwater by some residents. Dual-supply owners were often told by tradesmen not to worry about poor water quality, as they do not drink rainwater, but they use this experience to support their opinion of rainwater as dirty. Some residents reported indirect costs, such as this resident with dual-supply describes, 'We find that the laundry doesn't stay as white, and the toilets seem to get a film on them. The water doesn't stay clear like if we were using town supply'.

Learning process

Residents without prior experience in rainwater harvesting described many difficulties in learning to manage their water supply. Although the local government was

responsible for the regulation, their support in the learning process was often described as falling below expectations. One resident on sole-supply discussed his frustration with the regulatory agency, 'I think at the design stage, the councils could be a lot more helpful. We found that they didn't really give an awful lot of information at the time. I guess because if they gave advice, that turned out to be bad advice in the long run they would be liable'.

In lieu of public support, owners regularly turned to friends and 'experts' (plumbers, engineers, architects, and consultants) in the learning process. This increased the financial cost to residents and created inequalities. Many residents were not satisfied with their chosen expert, so they endured additional search costs. One resident on dual-supply describes the cost of a poor experience with one chosen expert, 'We had a problem with the pump … in reflection, the guy that set it up to start with didn't know how to set up a pump properly whereas the guy that I got in to sort it out – he was a proper guy who dealt with maintenance on pumps and water tanks – and he knew how to set it up properly'. To minimise the costs of experts, learning opportunities, particularly for dual-supply owners, were often reactive – advice was only sought when there was a system failure or visibly poor water quality.

Benefits

Net financial benefits

Sole-supply owners described how their exemption from water rates (taxes) made rainwater harvesting very cost effective from a financial perspective. One resident describes his operating costs as 'Not very much … The only cost is the electricity to pump it. To run the pump for an hour would cost us 23 cents and it runs for a few minutes so it's next to nothing I suppose. In our case there are financial benefits of having a tank'. Although all owners of sole-supply described a time when they paid to import water for an empty rainwater tank, most described this cost as a result of poor management or system failure (e.g. a leak), and viewed it as a learning opportunity.

In general, dual-supply owners did not describe net financial benefits, though one suggested that the net financial costs were lower than expected and forecast a net financial benefit in the future, 'I see the laundry benefit is it saves a bit of water but that's not a big cost, because it's only a few hundred dollars every six months. It probably saves NZ$500 a year … It's probably paid for itself over a period of about five years, based on what I can see of pricing at the moment which surprised me. I didn't think it would be that high'.

Control and freedom of use

In lieu of financial benefits, many residents on dual-supply viewed their stored water as a 'free' resource that enabled them to undertake discretionary activities to enhance their lifestyle. One resident suggests that this behaviour is specific to dual-supply, 'I would think to myself "oh we're on a rainwater tank, it doesn't matter if we water the garden, or empty the spa pool more than I normally would have", because it's not costing me anything for that water … sole supply would have a completely different perception of rainwater tanks, compared to someone like me'. However, many sole-supply residents also described benefits in regard to near-limitless consumption possibilities in wet winter months.

Detachment from water rates and the potential to avoid public rationing through self-management was seen as a benefit of having control over water supply as this sole-supply resident attests, 'when it's dry, we can't be told by the council when we can, and when we can't use the water. We have to make that decision for ourselves all the time, because we have to monitor our own water level. I guess it's only a small advantage – the self sufficiency'.

Intergenerational advantage

Some residents that reflected on the long-term benefits discussed how their children, having grown up with a rainwater tank, will have an advantage in a resource-constrained future. One dual-supply owner described how change would take place on a generational scale, 'I think the older generation are set in their ways. It's one of those things that they're probably not going to be able to realise. It will be my children that will say, "hey this is the way it is" '.

Enhanced personal values

Rainwater tanks were sometimes perceived as compatible with personal objectives relating to environmental conservation. As a result, owners gained satisfaction from being integrated in their environment and reducing waste, as this one resident with dual-supply attests, 'It's good to know you're utilising what comes off the roof rather than relying on town supply'.

Insurance

Having a secure water supply during a period of crisis led many residents to value their rainwater tanks. Interruptions

to town supply resulted in owners recognising that their home contained a water supply during the disruption. A dual-supply resident describes, 'I didn't actually appreciate my tank as much until recently, when we had a major breakdown in the water mains service. And all of the properties around had no water for 8–9 h, and I had my rain tank. I was just going about my usual task, and it was like, "oh, this is great" '.

Water quality

In contrast to owners expressing dissatisfaction with their rainwater quality, other residents felt that rainwater quality was far superior to city supply. Dissatisfaction in regards to the health and taste effects of chemicals added to centralised water supply was one driver, while knowledge (and control) of the supply chain for rainwater reassured some residents that their water supply was clean and healthy.

Learning process

While some residents found that the benefits of the learning process would fall mostly on their children, others described a number of indirect benefits arising from the collective need to adapt to life with a rainwater tank. One resident new to dual-supply rainwater harvesting describes how the learning process enhanced her sense of community, 'Everyone got to know everyone before the houses were built … it was really cool actually that when everyone moved in everyone knew everyone else'.

Four 'swing' characteristics

Resident perceptions differ in four aspects of urban rainwater infrastructure:

- security of supply,
- the learning process,
- water quality, and
- financial benefits.

The authors hypothesise that these features could represent the 'swing' characteristics of rainwater harvesting that will be important indicators for resident acceptance as well as the variables that should be targeted in policy intervention because there is potential for influence. Should future revealed preference studies indicate a positive correlation between rainwater harvesting provision and selling price, it may be indicative of a net positive outcome for these variables among the population of housing consumers.

Another important observation in regard to these four key outcomes is the degree that individual residents revealed internal debate when expressing opinions. Two outcomes – security of supply and the learning process – often presented internal conflict. For example, one dual-supply resident discussed how rainwater tanks were important for security of supply during natural disasters, and later described how he would not wish to change to sole-supply because city water would never 'run out'. Similarly, a desire to minimise the costs associated with learning, which could be financially expensive as most residents paid for expert advice, was conflicted with the desire to optimise water quality and tank management. Residents did not appear conflicted over their perceptions of water quality and financial benefits; but expressed clear and consistent opinions. A range of variables appear to influence their opinions, particularly past experiences in regard to water quality and the context around regulation and system design (dual- or sole-supply) in regard to financial benefits.

The importance of experience

When the interview data are examined from the perspective of experience duration, residents that have used rainwater harvesting for at least two years often view the four key aspects as benefits. This means that resident learning processes, or the development of empirical knowledge (as troubleshooting problems was often the key learning process for the residents), may be especially important. Less experienced residents report that they rely on 'experts' such as skilled peers, tradesmen, or local government, for advice on the rainwater systems. Often, this advice comes at financial and temporal costs, decreasing net benefits and utility. This relationship between experience and value supports the findings of Domènech & Saurí (2011), who found that residents of multi-unit complexes displayed a knowledge gap relative to residents of single-unit dwellings because the latter had more direct experience in the management of their rainwater tank. The inequity present in participant experience suggests that efforts to accurately produce a universal cost–benefit analysis for rainwater harvesting in New Zealand (e.g. Rabbitts 2009) will disguise high variability.

With similar outcomes in New Zealand and Spain, we present an economic hypothesis that needs to be tested more extensively. The marginal utility that residents place on increasing rainwater consumption appears to be a function of experience (empirical knowledge). Hence the standard assumption of declining marginal utility as

consumption increases does not appear to apply to the introduction of rainwater harvesting. For an inexperienced user, satisfaction with rainwater harvesting is low, but increasing empirical knowledge appears to increase the utility of rainwater harvesting. An example can be seen in the words of one dual-supply resident, 'I've changed because I've got one and I'm using it. So if people don't have one, they are not going to change … mine was forced on me, and I was quite miffed when I was building because it was essentially NZ$4,500 extra, but now that I live with it, and benefited from the advantages of it, and been able to realise, I have changed and I do think I really appreciate my tank'. The standard assumption of declining marginal utility (Krugman & Wells 2009, p. 252) may not be accurate for rainwater harvesting. The market for rainwater harvesting may behave more similarly to how Evers & Menkhoff (2004) describe booming South-east Asian knowledge economies.

Such a hypothesis has implications for government bodies considering mandatory rainwater harvesting as a solution to inefficient urban water management. Many urban residents face a steep learning curve following the introduction of rainwater harvesting. In this study, learning costs are borne privately and perhaps inefficiently, as learning often occurs following a system failure. Consideration should be given to short-term assistance for increasing empirical knowledge, perhaps in lieu of subsidies for infrastructure if resources are scarce. After an introductory period, which this study suggests is at least two years, residents will have learned from their experience of rainwater harvesting and can independently develop the ways in which they perceive, communicate and ultimately choose to manage their water resources.

CONCLUSIONS

This study describes the breadth of costs and benefits perceived by residents mandated to harvest rainwater in the largest city in New Zealand. Four aspects – security of supply, water quality, financial outcomes and learning processes – are valued either as a cost or a benefit, and may represent values of public acceptance. These values may help to explain future market trends; for example, observed price premiums in houses with rainwater tank infrastructure may indicate that the market values these four aspects as benefits (or costs if price discounts are observed).

Empirical knowledge gained by experience with managing a rainwater harvesting system can be important for public acceptance. Participants described how their satisfaction with rainwater harvesting increased with experience. When viewed using an economic framework, the marginal utility of an additional unit of rainwater consumption to inexperienced owners may be rising because that additional unit of consumption provides additional empirical knowledge. Consequently, mandatory rainwater harvesting could increase societal well-being.

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