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Water, water, everywhere…. Quantifying possible domestic water demand savings through the use of rainwater collection from residential roofs in Auckland, New Zealand

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ABSTRACT

Current residential sector growth rates in the Auckland Region are expected to impose increased demands on domestic water supply. This paper attempts to quantify, for four typical roof areas (100 m^2, 150 m^2, 200 m^2, and 250 m^2) of houses, the potential savings associated with domestic water supply from roof rainwater collection systems compared with using the city water supply system. The effects of trying to meet existing water demand figures are compared with what could be achieved by the promotion of flexibility in altering demands through technical and behavioural changes of the residents. Each of the four roof areas is examined under two scenarios. In the first scenario, the ability of the roof-collected water to meet conventional water demands is assessed, while in the second scenario the effects of water-saving techniques are assessed for their potential to allow households to achieve self-sufficiency in domestic water supply. The research takes into account the electrical energy used in delivering the city and on-site domestic water supply, water line-maintenance costs, network upgrades, and other charges for residential buildings compared with the capital and operating costs of using complete rainwater supply from roofs of houses.

INTRODUCTION

The Auckland Region, with a population of 1,158,891 (Statistics New Zealand, 2001a), consists of four cities (Auckland, Manukau, North Shore, and Waitakere) and three districts (Papakura, Rodney, and Franklin). Concerns about the future consequences of continuing to use traditional water resources has led to a paradigm shift that emphasises both demand and supply side management and the use of non-traditional water resources as an important aspect of promoting sustainability (Mitchell, 2004). It is important to understand how emerging new technologies could best be integrated into the existing urban systems to achieve useful outcomes.

METHODS AND RESULTS

Per Capita Water Use

The *Auckland Water Resources Quantity Statement* (2004) confirms that the main water use in the Auckland Region is in domestic households. The Statement calculates that 173 litres of water are used per capita per day for all household uses, such as drinking, cooking, washing and cleaning and flushing toilets (Bannister et al., 2004). This value has been derived from the initial calculations below (Table 1). The per capita water requirement per annum is calculated to be equal to 63,145 litres or 63 m^3. Water in the Auckland region is supplied by a number of different companies, each serving a different area. EcoWater, the company suppling water to Waitakere City, gives a breakdown of household water use as shown in Table 1.

Table 1: Household water use breakdown (Waitakere City Council, 2005)
Household Rainwater Collection

Water Use Categories	Percentage Breakdown	Water Use (litres per capita per day – averaged)
Kitchen	10%	17
Bathroom	25%	43
Laundry	20%	35
Toilets	25%	43
Garden	20%	35
TOTAL		173

In a given climate, the rainwater collection of a house will be fixed by its roof area and tank volume, while the water consumption of a household will vary depending on the number of occupants, the nature of the fixtures and equipment, and the behavioural choices of the occupants. If a household is to rely on collected rainwater, the amount of water that can be collected could be considered an important determinant of the potential occupancy of the house. Potential occupancy of a house is calculated below based on the estimated rainwater collection for four roof areas, ranging from 100 m^2 to 250 m^2. The total volume of rain-water collection from each typical roof area is calculated and then divided by estimated per capita water use to obtain potential household occupancy for the four roof areas based on rainwater collection. In this calculation it has been assumed that 10% of the roof water will be lost by evaporation (Waitakere City Council, 2001). Rainfall data for 2004 indicate that 2004 was recorded as one of the wettest years and the Auckland Region received 1331 mm of rainfall, which was 107% of the average annual rainfall (NIWA, 2004). The average annual rainfall for Auckland from these data was calculated to be equal to 1244 mm or 1.244 m.

Table 2: Total water collected from roof (m^3/annum)

Typical roof areas (m^2)	Total water collection from roof (m^3/annum) = Roof area (m^2) X 0.9 X average annual rainfall (m)
100 m^2	112
150 m^2	168
200 m^2	224
250 m^2	280

This potential water collection can be compared with the number of people that could be supported by this amount of water, based on the typical household water consumption figure of 173 litres per person per day from Table 1.

Table 3: Estimation of potential occupancy based on rainwater water supply

Typical roof areas (m^2)	Total water collection from roof (m^3/annum)	Potential occupancy based on 173 litres per person per day (no. of people)
100 m^2	112	1.8
150 m^2	168	2.7
200 m^2	224	3.6
250 m^2	280	4.4

Household Occupancy Status

A reasonable figure for the expected occupancy status of a house can be estimated from the number of bedrooms, on the premise that total potential occupancy is number of bedrooms +1. Some idea of the relationship between number of bedrooms and roof area can be found by examining sample plans from a large-scale house builder. The use of plans from a relatively ‘mass-market’ builder means the houses are likely to show more bedrooms for a given floor area than would be the case for more expensive houses, ensuring values for potential occupancy versus roof area are not under-estimated. Table 4 shows three ranges of houses from Keith Hay Homes (Keith Hay Homes, 2005), with floor area and number of bedrooms. The ‘First Choice’ ranges are the lowest cost houses, and the ‘Lifestyle’ ranges are the most expensive; reflected in the increased floor area relative to the number of bedrooms. The relationship between floor area and number of bedrooms varies very widely depending on the market at which the house is aimed. Looking at the range in Table 4 from just one manufacturer, a 2-bedroom house may range from 65 m^2 to 131.5 m^2 in area, a 3-bedroom house can vary from 75 m^2 to 174 m^2, and a 4-bedroom house from 95 m^2 to 203.8 m^2.

Table 4: House area and number of bedrooms (Keith Hay Homes, 2005)

"First Choice"			**"Classic Collection"**			**"Lifestyle"**		
Name	**Area**	**Bed rooms**	**Name**	**Area**	**Bed rooms**	**Name**	**Area**	**Bed rooms**
Plan 65	65.0	2	Barrie	66.0	2	BT1390	129.1	2
Plan 75	75.0	3	Austen	73.5	2	BT1420	131.5	2
Plan 85	85.0	3	Buchan	78.5	2	BT1594	148.0	3
Plan 85E	85.8	3	Carroll	85.0	3	BT1664	154.5	3
Plan 95	95.0	4	Shakespeare	90.0	3	BT1773	164.7	3
Plan 100	100.0	3	Courtney	96.0	3	BT1873	174.0	3
Plan 110E	109.6	4	Tasman	100.0	3	BT1903	176.8	4
Plan 120	120.0	3	Laurence	107.0	3	BT1909	177.3	4
			Flinders	120.0	3	BT2194	203.8	4
			Bronte	121.0	3			
			Kingsley	130.0	3			
			Stanley	139.0	4			

Roof areas can be assumed to be typically around 10% to 20% larger than floor areas, depending on roof overhang. In Table 5, roof areas and numbers of bedrooms have been allocated based on the data from Table 2, to give an idea of the gap between the available water from the roof and the likely demand.

Clearly even a large house with a correspondingly large roof cannot supply the water needs of its likely number of occupants, based on the water consumption of a typical Auckland consumer. This makes the use of rainwater tanks appear unattractive, as any development will need the installation of reticulated water as well as rainwater systems, adding significantly to costs.

Table 5: Interrelationship of roof areas, number of bedrooms and water supply

Typical roof areas (m^2)	**Water collection from roof (m^3/ annum)**	**Potential occupancy based on available water (no. of people)**	**Assumed no. of bedrooms**	**Potential occupancy based on no. of bedrooms (no. of people)**	**Required water supply for occupancy @173 lcd (m^3/ annum)**	**Percentage of water supply that could be provided by rainwater**
100 m^2	112	1.8	3	4	253	44%
150 m^2	168	2.7	4	5	316	53%
200 m^2	224	3.6	5	6	379	59%
250 m^2	280	4.4	6	7	442	63%

However, water demand is not fixed, and there are a range of technical options that can reduce water demand. Table 6 shows the savings in household water consumption that can be achieved by the use of relatively simple and low-cost technical changes, which are detailed in the table.

Table 6: Domestic water consumption reductions through use of water reduction fixtures

Household water use scenarios	Per capita daily flow allowance (litres per person per day)	Per capita annual flow allowance (m^3/ annum)
1. Dwellings with **standard water use** facilities (11 litre toilet; automatic washing machine; standard shower heads; standard taps)	200	73.0
2. Dwellings with **standard water reduction** fixtures (dual flush 11/5.5 litre toilet; showerhead flow restrictors; aerator taps; water conserving washing machines)	180	67.7
3. Dwellings with **enhanced water reduction** fixtures (dual flush 11/5.5 litre toilet; showerhead flow restrictors; aerator taps; water conserving washing machines plus Fixed Orifice Flow Control (FOFC) valves on all outlets)	140	51.1
4. Dwellings with **full water reduction** fixtures (dual flush 6/3 litre toilet; showerhead flow restrictors; aerator taps; front load washing machines plus Fixed Orifice Flow Control (FOFC) valves on all outlets)	90	32.9

(I. Gunn, 2000, quoted in Parliamentary Commissioner for the Environment, 2001)

The four scenarios in Table 6 do not include any attempt to recycle water or any changes in user behaviour. (Note: The starting point of the scale in Table 6 (200 litres per person per day) gives an annual per capita consumption of 73 m^3 per person, which is greater than the domestic demand of 63 m^3 per person per year shown under per capita demand section). The demand reduction scenarios in Table 6 allow the construction of Table 7, in which the possible reductions are applied to the roof areas and occupancies from Table 5.

Table 7: Interrelationship of roof areas, number of bedrooms and water supply

Typical roof areas (m^2)	Potential occupancy based on number of bedrooms (No. of people)	Water demand under Gunn's four demand-reduction scenarios (m^3/ annum)				Water collection from roof (m^3/ annum)
		1	2	3	4	
100 m²	4	292	271	204	132	112
150 m²	5	365	339	256	165	168
200 m²	6	438	406	307	197	224
250 m²	7	511	474	358	230	280

It can be seen that all houses could be self-sufficient in water with the exception of the four-person-house with the 100-m^2 roof, which it appears can obtain only 85% of its water supply from a rain water system. However, this may be a pessimistic assumption, as water demand is highly flexible, as can be seen by looking at situations where rainwater forms the sole water supply.

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Living without Mains Water

About 10% of the New Zealand population relies on collected rainwater for water supply (Fleming, 2000, quoted in Abbott *et al*., 2004). An example of a community that uses rainwater is Waiheke Island in the Hauraki Gulf off the coast of Auckland. The island had a permanent population of 7,137 in the 2001 Census of Population and Dwellings, and the population was growing about four times faster than the population of New Zealand as a whole (Statistics New Zealand 2001b). The population is also swelled in summer by holidaymakers. While a few households have boreholes, this is not common, and the large majority of households use roof water for all water needs, as there is no reticulated water supply. . The typical rain water tank on the island holds 25,000 litres, which is the largest that can be installed without the need to obtain special planning consent. Most people drink the water without any treatment. It is interesting to note that the non-availability of mains water has not stopped the rapid development of the island as a commuter suburb, with an increasing number of large and expensive houses being built.

Anecdotal evidence from Waiheke (where one of the authors has lived for the past 9 years), is that locals do not tend to run out of water, whereas holidaymakers often do. This suggests that where people are used to having rainwater as their sole water supply, they tend to conserve water, as it is inconvenient to run out. A further, international, example can be seen in the Autonomous House, built in the centre Southwell, England (annual rainfall 576 mm), in 1993. The house was occupied by a family of two adults and two teenagers. Its sole water supply came from rainwater collected from the roof and stored in a range of tanks in the basement; storage volume was 30,000 litres. To reduce demand for water it used waterless composting toilets. All necessary Building Regulations consents were granted. The Autonomous House had measured water consumption of 34 litres per person per day, or 49.6 m^3 per year, (see Table 8 for a breakdown) but in spite of this, the Building Research Establishment reported that no loss of amenity to the occupants could be discerned (Vale & Vale, 2000). Even when the water used for toilets and the garden was removed from consideration, the Autonomous House water consumption is one third of the Auckland average.

Table 8: Autonomous house water use compared with Auckland average

Water use categories	**Percentage breakdown – conventional**	**Water use – conventional (litres per capita per day, averaged)**	**Percentage breakdown – conventional excluding toilets and garden**	**Water use – Autonomous House (litres per capita per day, averaged)**	**Percentage breakdown – Autonomous House**
Kitchen	10%	17	18%	7	20%
Bathroom	5%	43	45%	21	62%
Laundry	20%	35	37%	6	18%
Toilets	25%	43		-nil	
Garden	20%	35		-nil	
TOTAL		**173**		**34**	
TOTAL excluding toilets and garden		**95**		**34**	

A case study from Carindale Pines, Brisbane, Queensland, Australia (31 households on a 14-ha site), estimated that 70% to 80% of residential demand was supplied by rainwater tanks, including drinking water; savings in potable water usage in comparison with conventional design were more than 80% (Mitchell, 2004). Evidence that water demand is likely to be very low in a situation where a rain tank forms the sole supply suggests there may be benefits in providing houses with rainwater systems for all water supply, rather than seeing the tank as a way to reduce the load on the reticulated water supply. People may tend to conserve water if the alternative is to run out.

Energy Demand for Water Supply

A domestic rainwater system usually employs an electric pump to deliver the water to the taps. Will this result in higher energy consumption than the reticulated system? A high-quality specification for a domestic rainwater system pump is the Grundfos CH250, which is made of stainless steel, and pumps 775 gallons (3500 litres) per hour at 40 psi, using 680 Watts/2.9 A. It has a life of 15 years. (The Tank and Pump Shop, 2005). These figures mean that domestic water pumping is likely to use in the region of 0.2 kWh per m^3 (0.194 kWh per m^3). Some idea of the operating energy demand of the reticulated water system can be obtained from Watercare (Watercare, 2003), who report total annual sales of 124.5 million m^3 of water in 2002/3, with 14,900 mWh of electricity used for water supply, and 7,430 mWh for water distribution. This gives a figure of 0.179 kWh per m^3, but only within the Watercare system, so no account is taken of the energy used by the whole water supply system. Use of a domestic pump is therefore unlikely to result in increased energy use compared with the energy used by the reticulated supply.

Costs of Water Supply

Water costs from Metrowater, the company that supplies Auckland City (Metrowater, 2005a) are calculated as follows:

Service charge	$30 per year
Wholesale charge	$0.515 per m^3
Metrowater network charge	$0.66 per m^3

A standard new water connection (20 mm) costs $580.

In addition to all the charges mentioned above, there is a one-off charge for the initial connection to the water system. This Network Upgrade Charge is levied on each new dwelling, and is $2126.25 Inc GST (Metrowater, 2005b).

To obtain an estimate of costs in a situation where rainwater tanks and their associated systems are in common use, prices for tanks and pumps were obtained from a supplier on Waiheke Island. These costs may be higher than in a similar situation on the mainland, because of the transport costs of shipping items to the island. A plastic tank of 25,000 litres capacity costs $4,500 installed, which includes earth moving to make a level base, sand bedding, plumbing from downpipes to tank, and plumbing from tank to pump. Cost of a filter for the water entering the tank is $268, which gives a total cost of approx $4,800. The assumed life of the plastic tank is 75 years. The cost of a Grundfos CH250 pump is $855 (The Tank and Pump Shop, 2005). The installed cost of the pump is approx. $1,000; the assumed life is 15 years. At around $5.00 per year for the largest household, electricity costs for pumping are negligible.

The net present values of the cost of water (NPV) for a period of 75 years (estimated life of a plastic rainwater tank) at a discount rate of 7.5%, including service charge and network upgrade charge per annum, have been calculated, based on 63 m^3 of water requirements per person per annum consumption for four household sizes, for a four-person household with reduced mains water demand (refer Table 7), and for a rainwater-only house with a typical rainwater tank of 25,000 litres. Similarly, NPVs for all these options are also calculated assuming 7 years as the average length of ownership of NZ property. All expenditure costs are GST inclusive unless otherwise stated. These figures allow the construction of Table 9.

Table 9: Cost of typical water consumption from reticulated and rainwater supply

Typical roof areas (m^2)	Assumed no. of bedrooms	Potential occupancy based on no. of bedrooms (no. of people)	Water supply based on occupancy @173 lcd (m^3/annum)	Cost of water inc service charge and network upgrade charge ($NZ per annum)	Net Present Value for a period of 75 years ($NZ)	Net Present Value for a period of 7 years of property ownership ($NZ)
100 m²	3	4	253	$327	$6862	$4,251
150 m²	4	5	316	$401	$7845	$4,643
200 m²	5	6	379	$475	$8827	$5,035
250 m²	6	7	442	$501	$9810	$5,427
100 m² (4 person household)	4	4	112 (reduced demand from Table 7)	$162	$4663	$3,373
25,000 litre Rainwater Tank	-	-	-	$5 (electricty cost for pumping)	$5901	$5,392

It can be seen from NPV comparisons between roof rainwater supply and conventional demand from reticulated water for a period of 75 years, that rainwater tanks appear financially attractive for four typical roof areas. For a short term of 7 years, only larger roof areas of, for example, 250 m², show financial householder advantages for investment in rainwater tanks. The four-person household with reduced demand, however, could buy reticulated water of the same quantity as that provided by their roof (112 m^3 per year) at an NPV lower than the cost of rainwater supply, even taking into account the 75-year time frame. These calculations include no maintenance costs or possible filtration and treatment costs of using rain water collection systems, which may offer different results.

CONCLUSION

There may be little point in recommending the use of roof rainwater-collection systems for domestic water supply if such systems are unlikely to be capable of supplying a useful quantity of water. Clearly, these figures begin to answer only the most basic questions about rainwater use. They show that household rainwater collection could supply an adequate amount of water, at least in Auckland, and that the cost of doing this may not be greater than that of conventional water supply in the long term. However, the costs considered here do not address the cost of filtration and treatment systems for rainwater use, which may be demanded in the future in spite of their non-use in existing communities such as Waiheke Island. Figures presented here suggest a possible argument for considering rainwater systems for the water supply of new developments, while leaving the existing water system to supply existing dwellings. This would avoid the costs of duplication and the need to enlarge the existing infrastructure.

Significant benefits to storm-water management can also be achieved through the use of rainwater tanks, with tanks used to compensate for impervious areas (ARC 2003), and this could lead to further cost benefits. Indeed, if rainwater is to provide a cost-effective solution, it may need to be able to supply all of a household's water demand, otherwise there will be a duplication of systems with a consequent increase in costs as a result of installing supplies for both reticulated water and rainwater. While further research is needed to ensure there are low-cost ways to allow rainwater systems to provide an effective and safe water supply for users, the figures presented here at least suggest this could be worth pursuing.

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