RAINWATER TANKS IN THE URBAN ENVIRONMENT – FRIEND OR FOE?

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ABSTRACT

The harvesting of rainwater is preached as sustainability in all cases. This paper addresses the issues associated with installing rainwater tanks in the urban environment as a supplement to a reticulated supply. The results of modeling of rainfall and water demand on a household basis are presented complete with the assumptions and limitations of the modeling. The assumed variables are adjusted to examine the effects on the sustainability of the supply throughout the year.

This paper challenges the widely held belief that rainwater tanks are sustainable and always:

- Reduce the demand on the reticulated supply.
- Conserve natural resources.
- Reduce the consumers costs

This paper demonstrates that the installation of rainwater tanks for supplementary water supply is not a cost effective proposition and offers no benefits to the size of the water treatment plant and water supply network. Economic and environmental benefits may be achieved in delaying future water sources if the current water source is stored water (dam, lake, aquifer, etc.). However, if the source is a river, then any environmental or economic benefit is at best marginal.

KEYWORDS

Rainwater Tanks, Rainwater Harvesting, Supplementary Supplies

1 INTRODUCTION

Over the last few years there has been a significant emphasis on the conservation of water for water supply and a view that harvesting rainwater on a household basis is beneficial to this ideal. In principal the idea of harvesting rainwater for some or all of a household supply sounds like a good idea and indeed in Australia appears to be a necessity. In this paper, the modeling presented represents only certain areas in New Zealand and has been confined to the upper North Island. However, the conclusions reached should be applied when considering encouraging or mandating the use of rainwater tanks in the urban environment.

In rural environments where there is no reticulated supply, rainwater tanks may be the only source of water and may supply the total household. In this paper, the urban environment with a reticulated supply only is considered. The rainwater harvested from the roof will be used to supplement the reticulated supply, not replace it.

The approach to deciding on the merits of rainwater tanks involves building a model for the specific urban area in question. This model uses actual rainfall data along with average roof areas, a defined tank size and an average annual household demand to model the volume of water in a tank over the year. The output from the model is then used to determine the number of days a tank will be without water. This is important in determining the effect on the reticulated network, the cost balance of the rainwater tank system, the sustainable supply from rainwater and the tank size required.

2 THE SUPPLEMENTARY RAINWATER TANK SYSTEM

The diagram below shows the recommended rainwater tank installation for a North Island Council. This diagram shows the necessary installation for a rainwater tank for potable or non-potable water supply. The major difference between a potable and non-potable supply is the degree of treatment required after the pump from the tank. A potable supply will typically have a number of filtration stages with the last stage being a protozoa rated cartridge. A non-potable supply will have filtration but may stop with a 5 micron filter. Additionally, some form of disinfection (UV or hypochlorite) may be installed on a potable supply where as for a non-potable supply, any disinfection is likely to be periodic shock dosing with hypochlorite. In this paper only non-potable supplies are being considered.

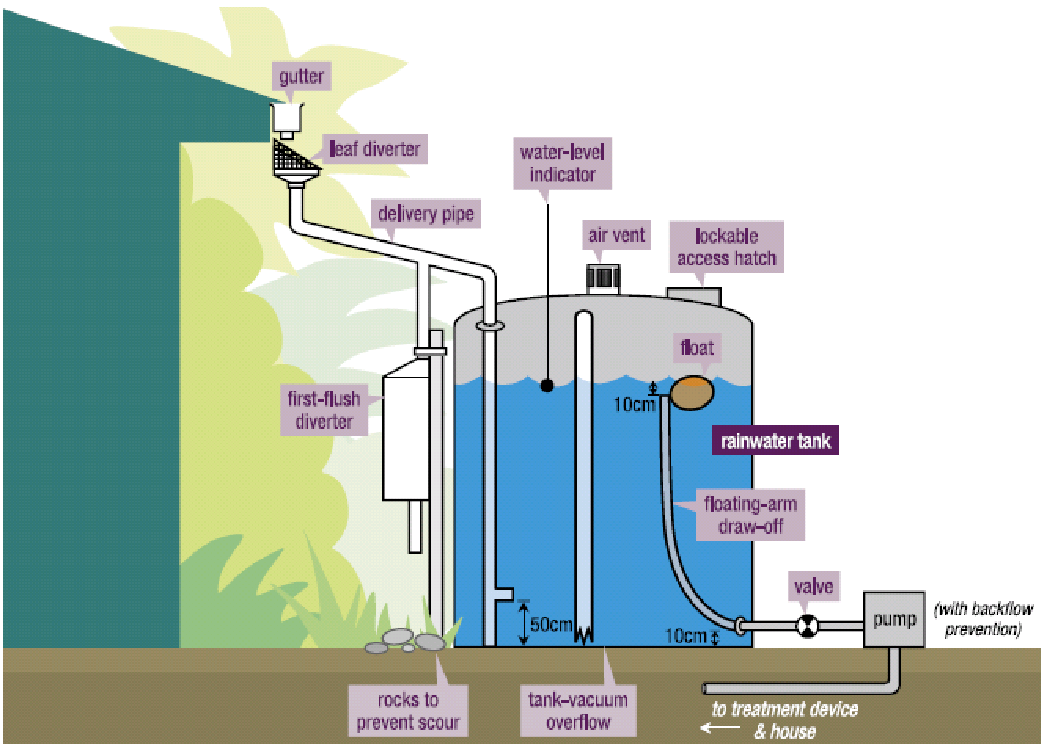

Figure 1 - Rainwater Tank Recommended Installation

Of interest in this diagram is the amount of equipment recommended to supply water to a household. Even if this tank supplied only the outside usage, the only item that may then not be required is the pump. However, if the tank is used to supply the toilet also, then a pump will be required.

Instead of providing a consultants estimate of the system, a plumber was approached to install a 5,000-litre tank with all the equipment shown in the above diagram. Costs included a base for the tank and connecting all the household down pipes from the roof to the tank. The estimate provided was a budget price with a large unknown for the connection of down pipes. The estimate for this work was approximately $7,500.

This price may seem extremely high when compared to the cost of a standard 5000-litre tank. However, this is the installed cost of the system, not the purchase price of the equipment. This cost also includes getting someone else to do the work. Costs can be reduced by undertaking the installation work by the homeowner. However, for the purposes of this paper, it is assumed that the installation will require the input of a specialist plumber as this is the likely scenario for most people.

3 BUILDING THE MODEL

3.1 ASSUMPTIONS

In generating the model, the following assumptions must be made:

- Roof area
- Household demand based on:
    - Usage per person per day
    - Occupancy
- Split between inside and outside usage (typically 20% of household demand is outside usage)
- Amount used for toilet flushing
- Tank volume
- Amount of rainfall required prior to effective harvesting.

The roof area really depends on the area where the model is being generated and whether the houses are single or two storeys. In the model presented below the effect of varying the roof area in a dry year will be examined. In the models below it is assumed that rainwater may be collected from the entire roof area.

Household demand is again area dependent with different areas having varying per capita demands and occupancies. The per capita usage and occupancy can vary significantly depending on region, giving very different demand profiles. The demand figures can be further refined by using an average summer and an average winter demand or by using actual daily demand figures.

The water consumption for outside usage is set at 20% and the amount used for toilet flushing is estimated at 25%. These figures are based on figures supplied in the Rodney District Council brochure on rainwater tanks for non-potable usage. The split between indoor and outdoor usage may also be area dependent and must be reviewed based on the area to be modeled.

For a supplementary supply, a 5,000-litre working volume tank is assumed. Again varying the tank volume will be demonstrated.

When rainfall occurs, there will be some rainfall that does not reach the tank. For the purposes of this model, it is assumed that any rainfall less than 2mm will not be harvested – this is partly due to the assumption that a first flush diverter is used and partly due to leakage and losses..

3.2 DATA REQUIREMENTS

The most important aspect of this assessment is the obtaining of reasonable rainfall data for the area concerned. The use of average rainfall in justifying rainwater tanks is dangerous and must be avoided. Actual daily rainfall data provides a real input into a model that is otherwise based solely on assumptions.

In most cases it is important to model a worst case and an average case. The worst case may be a known dry year or, for more justification, 50 or 20 annual return interval years can be taken. For example, the year used in the model is, for a dry year 1993/94 and for an average year 1989/90. The rainfall data is for Warkworth about 80km North of Auckland and are based on daily rainfall figures from 1921 to 2007. The driest year on record appears to be 2000/1. The 1993/94 rainfall is the next driest year and is approximately 200mm more than the driest year. The average rainfall is within 50mm of that from 1989/90. It should be noted that the median and mean averages are within 8mm of each other.

When selecting data, the effects of global warming should be at least considered. The amount of rainfall is likely to change over the years. What is now a 50-year ARI drought may be a 40-year ARI drought in 20years time. By selecting what is regarded as an unusual event now may seem overly cautious but given that global warming is likely to reduce rainfall in some areas, this may reflect the future reality.

3.3 MODEL CALCULATIONS

The calculations are a relatively simple mass balance with some adjustment for the efficiency of the collection system. The volume remaining at the end of the day is calculated as follows:

Volume Remaining = Volume in – Volume out

The volume in is calculated from the rainfall and the roof area with adjustments for low rainfall and losses. The rules are listed below:

- If the rainfall event is less than 2mm then no water is harvested
- In any rainfall event over 2mm, all the rainfall is harvested except for the first 2mm.
- The remaining rainfall is then multiplied by the projected roof area to obtain the volume entering the tank.

The volume out is based on the premise that 45% of the total demand is for outside and toilet flushing usage on a daily basis. This is clearly not necessarily true as people are less likely to water their gardens or wash their cars when it is raining. It is more likely that the demand during dry periods for outside usage is higher than that estimated in the model.

Conversely it is also true that the outside usage is likely to be lower during wet periods. This has the impact that the tanks have less capacity to store additional stormwater during wet periods as tanks will reach capacity sooner.

By using a daily demand of 45% of the total household demand from rainwater tanks, the model will predict less days without water and shorter periods of no water than actually occurs. The model will also predict that more water will be harvested than will be harvested in reality due to an unrealistically high outdoor usage during periods of wet weather. Accepting this constraint, the demand figures can be based on actual demands for the area considered.

The model is capped to prevent volumes over the tank maximum or volumes less than zero from occurring.

4 MODEL RESULTS

The model was developed to investigate the possible benefits of installing rainwater tanks in an urban environment from the perspective of a water supplier.

The first scenario modeled is on a household with three people in residence using a total of 540-litres per day. Of this 240-litres is supplied from the rainwater tank.

The roof area for collection is 160m2. The tank working volume is 5,000-litres.

The rainfall data used in the first run of the model (figure 2) is for Warkworth for the year 1993/94 (a dry year in that area). The rainfall data used in the second model (figure 3) is for the year 1989/90 and is close to the rainfall for an average year.

The premise is that the tank starts full. As can be seen from figure 2, there are significant periods in the summer when the tanks would have been empty. The total number of days when the model shows zero is 47 and the longest duration of a period of zero volume is 18 days. If the rainfall data is now changed to an average year the following graph may be generated using the same parameters.

From the results from an average year shown in figure 3 there are 42 days where the rainwater tanks run dry and the longest duration is 19 days before the tank regains any volume. Clearly based on the demand, tank size and roof area available, this system cannot provide sufficient water for over 10% of the year.

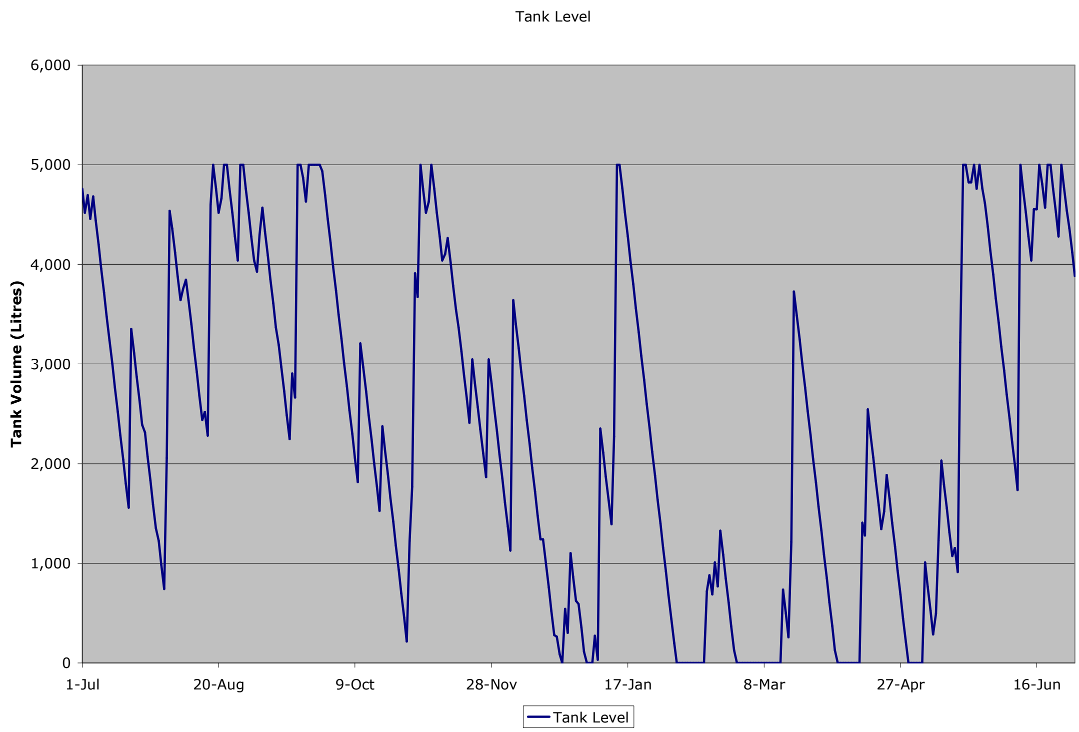

Figure 2 Tank Volume over the year 1993/4

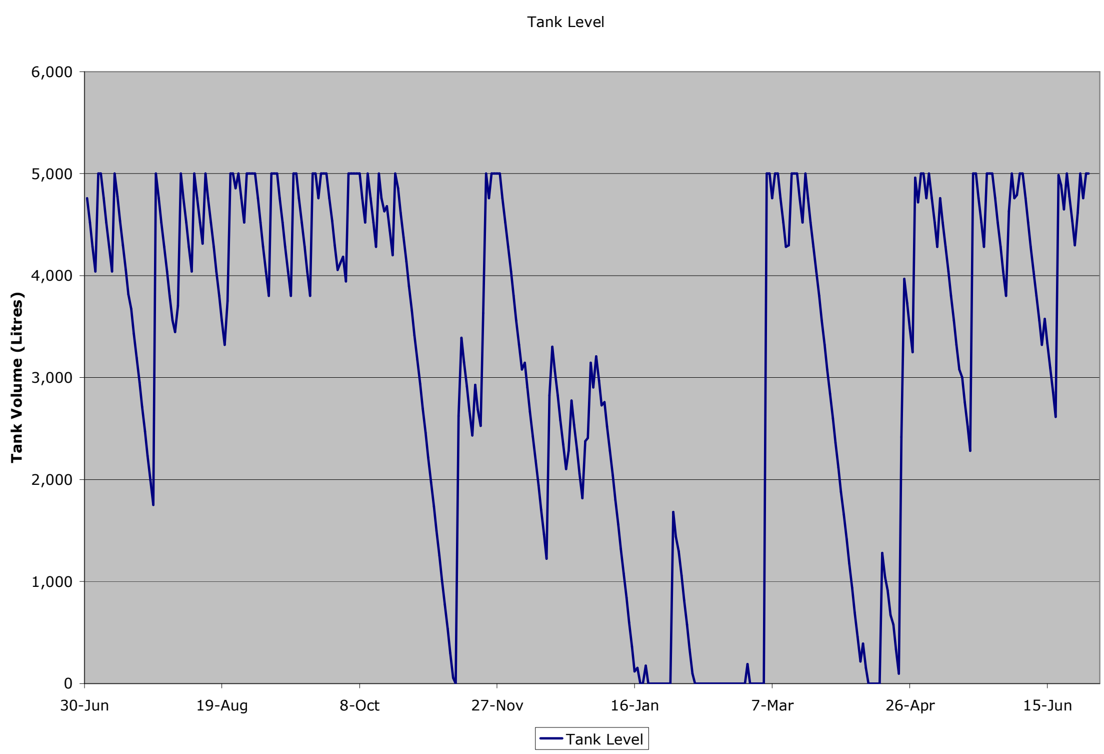

Figure 3 Tank Volume over the Year 1989-1990

4.1 REVISING THE DEMAND

Based on the same roof area, rainfall, tank size and rainfall data for the dry year, the model was re-run to determine the sustainable demand from this tank. The following graphs show the tanks volumes with sustainable demands based on a 160m^2 roof area and a 5000-litre tank.

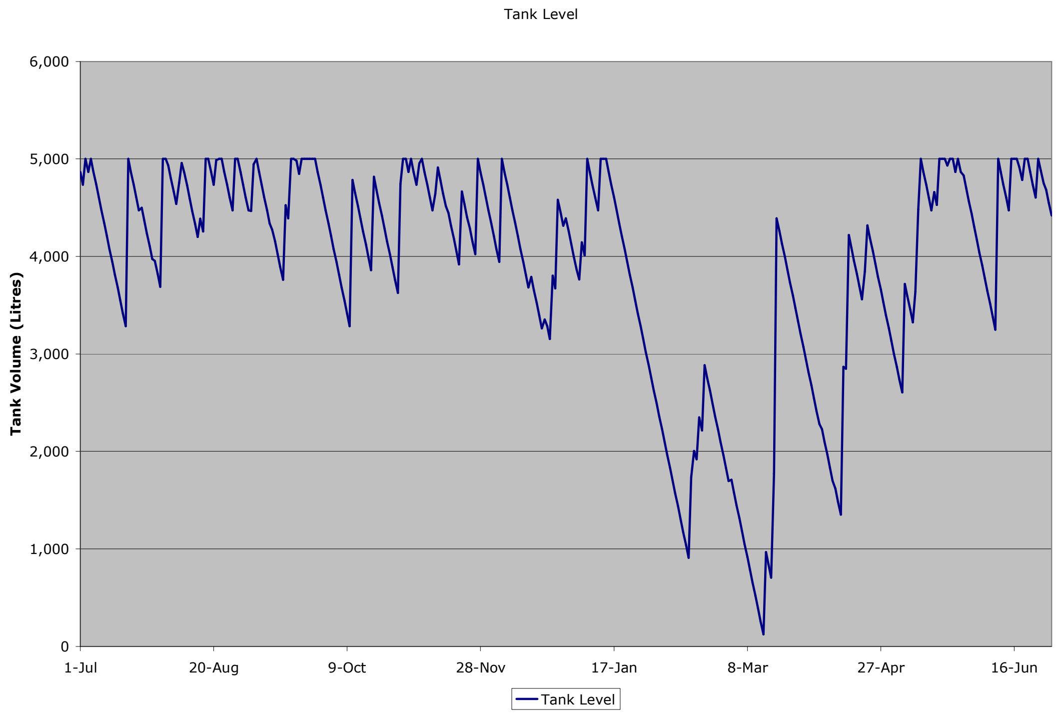

Figure 4 Tank volume Dry Year Reduced Demand

To achieve a sustainable supply based on the above parameters, the demand must be reduced to around 132-litres per household per day or a reduction of approximately 45%. This corresponds to just supplying the needs of the toilet with no outside usage. In an average year the reduction is slightly less at 40%.

4.2 INCREASING THE TANK SIZE

If the demand is reset to 240-litres per household per day and the tank volume is varied, a tank volume of approximately 14,500-litres is required to ensure supply during a drought year as shown in the figure following:

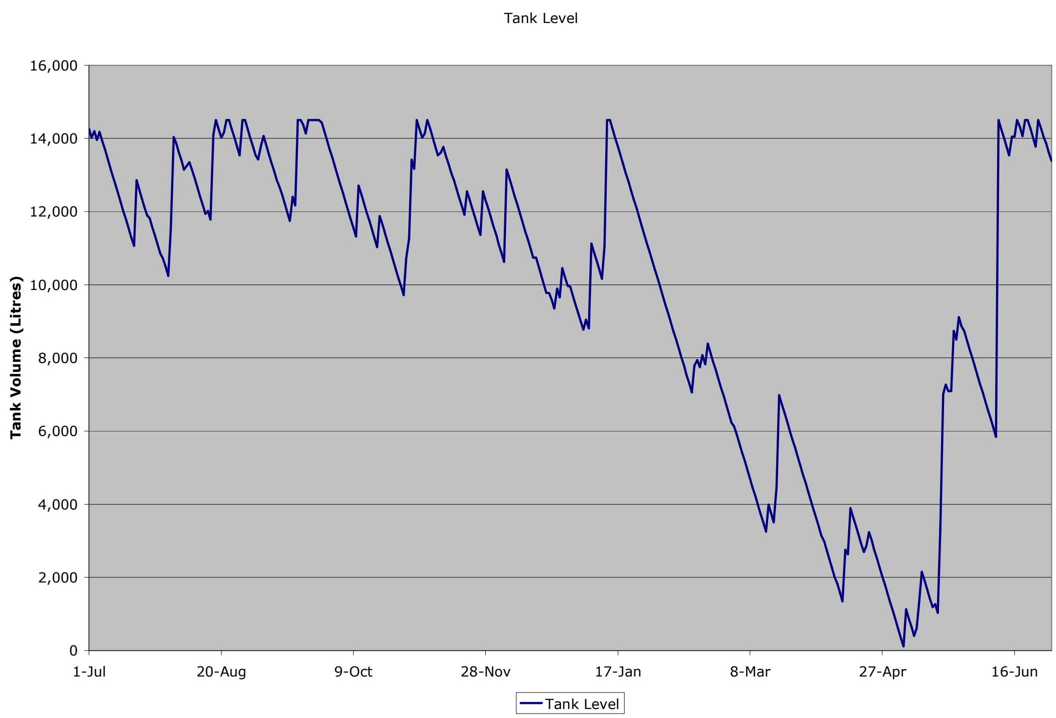

Figure 5 Tank Volume Dry Year (14,500-Litre Tank)

In an average year the model shows that a tank of about 13,000-litres is required.

4.3 INCREASING THE ROOF AREA

As the roof area is varied, it becomes clear that the roof area is as not as large a factor in providing a sustainable supply compared to adjusting demand and/or increasing the tank size. Even when the roof area is increased to 1000m^2 and an average year rainfall is used, there is still a day when the tank empties (see figure below).

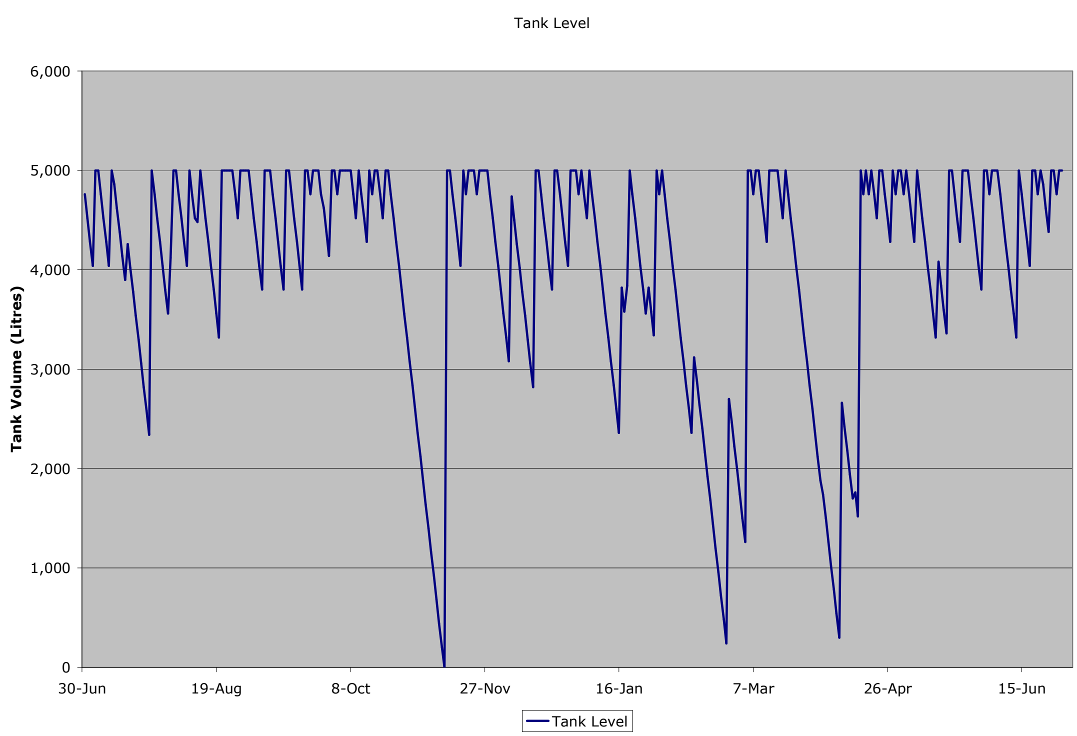

Figure 6 Tank Volume Average Year Rainfall Roof Area 1000m²

Clearly for a dry year the roof area would be greater to ensure a sustainable supply.

4.4 COMPARISON OF TANK LEVELS TO RIVER FLOWS

As noted before, the rainfall data used is from Warkworth. The water source for Warkworth is currently the Mahurangi River. Comparison of the tank levels with the flows in the river over the summer, generate the following figure:

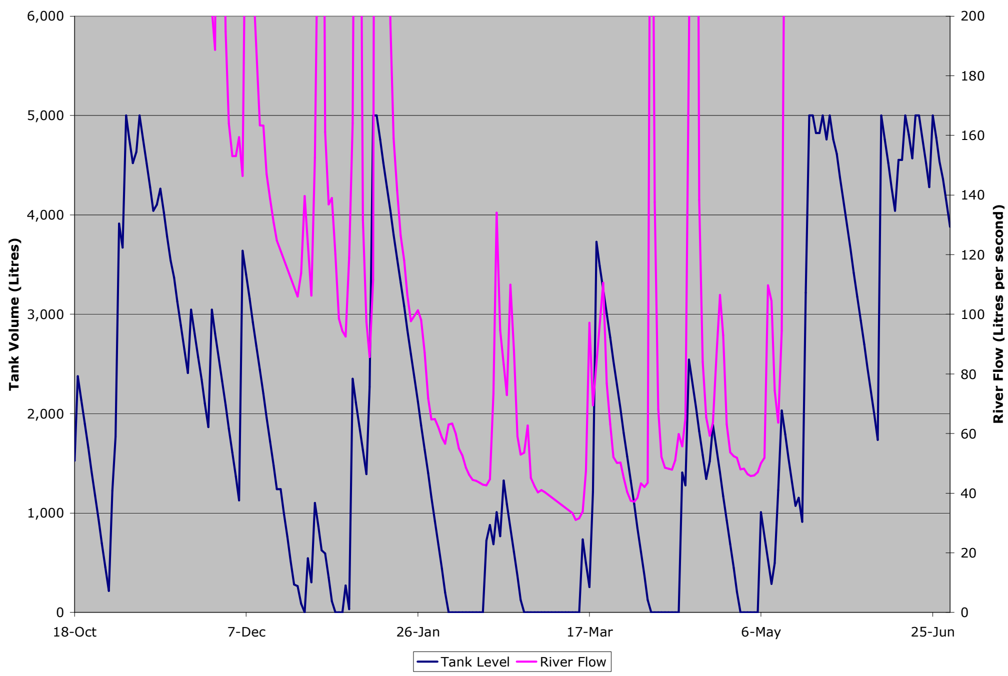

Figure 7 Tank Levels against River Flows

It is perhaps obvious that the tank volumes and river flows will both be low after a sustained period without rainfall. It should be noted that during the period of low flows shown here, the natural flow in the river is less than the residual flow required by the resource consent to be maintained in the river after water supply abstraction. What this indicates is that the rainwater tanks are empty when the supply is constrained thus offering no benefit to the stressed water supply.

5 THE COST OF RAINWATER TANKS

5.1 INDIVIDUAL COSTS

The results appear to indicate that a 5,000-litre tank and 160m² roof cannot support both the toilet flushing needs and the outdoor usage of a household of 3 people who use on average 180-litres per head per day. The mode indicates that at least every other year, the household will have to purchase approximately 10m³ per year of water. Recent enquiries have shown that the cost of the tankered water is approximately \$15/m³. This would give a cost of approximately \$150 every other year or an average annual cost of \$75.

If the cost of water is \$3.25/m³ in the township in question, then the total bill for the year is approximately \$640 per year (variable cost). The water saved is approximately 80m³ or \$260 per year.

If the cost of installation of the rainwater tanks is considered, \$7,500 (see section 2) and spread evenly over 25 years, this gives an annual cost of \$300 per year.

If the cost of maintenance of the rainwater system is excluded the economic balance is:

Install cost (annualized) + Tanker Water Cost (annualized) – Savings in Water bills

or

$300 + $75 - $260 = $115

The savings in the annual water charges are also not necessarily fixed. A recent investigation looking at the variable and fixed costs of a water supply indicated that between 80% and 90% of the costs of producing water were fixed. These included salaries, overheads, depreciation, etc. The variable costs were chemicals, power and a proportion of the maintenance.

If sufficient proportions of the area supplied by a water provider were to move to rainwater tanks, the effective demand might be cut significantly (by up to 40%). Given that 80% of the water providers costs are fixed and must be covered by the water charges, the only option is to increase costs to cover the fixed costs.

For example, to calculate the amount of saving that a household would achieve if a 40% reduction in the reticulated supply was achieved, it is necessary to work out the revenue from the water based on the current water charge and then compare this to the necessary revenue for the reduced demand. The revised cost per cubic metre can then be worked out from the revised production and the revised revenue required. Assuming that the water charge is $3.25/m^3$ and there are 1000 households each consuming 540-litres per household per day:, the following calculations can be carried out.

Annual Demand	= 540/1000 x 1000 x 365	=197,100m^3/year
Annual Income	= $3.25 x 197,100	= $640,575
Fixed cost at 80%	= 0.8 x $640,575	= $512,460
Variable cost	= 0.2 x 3.25	= $0.65/$m^3$
Saving due to rainwater tank installation	= 40% x 197,100	= 78,840 m^3/year
Actual reticulated water supplied	= 197,100 – 78,840	= 118,260m^3/year
Cost of reticulated water supplied	= fixed costs + variable costs	
	= 512,460 + [118,260 x 0.65]	= $589,329
Cost per cubic metre	= 589,329 / 118,260	= $4.98/$m^3$
Cost per household	= 4.98 x [540/1000 x 0.6] x 365	= $589/year
Predicted reticulated water saving	= $640 - $589	= $51 per year (8%)

As can be seen from the above calculations the unit charge rises from $3.25 per cubic metre to $4.98 per cubic metre or a rise of 53% on the unit price of water. The savings achieved are actually closer to $51 per year rather than the $260 per year indicated above. In this example, the annualized cost of rainwater tanks can be recalculated as follows:

$300 + $75 - $51 = $324

5.2 COMMUNITY COSTS

5.2.1 WATER SOURCE PLANNING

Where the water source is a run of the river and there is no stored water, the installation of rainwater tanks offers no benefit to resource conservation. In a river where a consent is granted, the water must be used with the timeframe (normally 24 hours) or it is lost. As has been demonstrated in the model, there are periods at least every other year where the rainwater tanks are empty. In figure 7, this corresponded exactly when the river flows were low. If at anytime during the year the tanks become empty, the source water must be able to supply the full demand.

Where water is stored, such as a dam or an aquifer, the installation of rainwater tanks may delay the need for an additional water source to cater for growth. However the cost of the new water source must be weighed against the cost of installing rainwater tanks. It is a simple calculation, if the cost per household for the new water source is less than the cost of retrofitting rainwater tanks to existing properties and installing rainwater tanks in all new properties, then the correct economic answer is to build the new water source. It is recognised in this that there may be additional environmental or social issues associated with a new dam or aquifer that may override the economic balance.

5.2.2 WATER SUPPLY NETWORK

As can be seen from the model, the instantaneous demand for water from the reticulated supply is likely to be at least the same during dry periods whether rainwater tanks are installed or not. Even if water tankers are used to fill up empty tanks it is likely that these tankers will be filled from the reticulated network. However, it is much more likely that those with empty of near empty tanks and a reticulated supply will simply fill their tanks from the network. It is difficult to prevent the public from filling their tanks during periods of dry weather in this manner and almost impossible to police. This means that the demand on the network is at least what it would be if no rainwater tanks are installed. It is likely that the instantaneous demand could be higher than a system without rainwater tanks as there could be a sudden increased daily demand as a large proportion of the population fill their empty tanks from supply. It is therefore unlikely that any water treatment plant or treated water storage installed could be reduced in size due to the installation of rainwater tanks. There are therefore no identifiable savings in the reticulated water supply system.

Given that the network must be sized for the demand as if rainwater tanks were not available, this can cause another problem – that of residence time of the water in the reticulation. For example, if the demand on a supply without rainwater tanks is 1,000m^3/day and there is 1,000m^3 of storage available, then if rainwater tanks reduce the demand by 40%, the residence time climbs from 24 hours to 40 hours. Whilst 40 hours may not be a problem in itself, it may require additional chlorine dosing to ensure chlorine residuals are maintained at the ends of the reticulation.

5.2.3 STORMWATER

Whilst stormwater control is not within the scope of this study, rainwater tanks can provide benefits in terms of stormwater control. ARC's TP10 Design Guideline Manual Stormwater Treatment Devices states, "Rainwater tanks are primarily water quantity management devices. There are minor water quality benefits." There is an entire chapter dedicated to the design construction and maintenance of rainwater tanks in TP10.

Rainwater tanks may provide storm water attenuation in a 1 in 2 year event or even a lesser frequency event. However, the reticulated storm water system will typically be designed for a much more infrequent event. During this event the rainwater tanks are assumed to be full for design purposes. There is no cost benefit therefore, to the installation of rainwater tanks. Depending on the receiving environment, there may be some benefit to the environment during the higher frequency storm events.

The installation of rainwater tanks for stormwater control needs to be addressed on a catchment by catchment basis and offers no overall benefit if the rainwater tanks are installed on a piece-meal basis. For rainwater tanks to operate effectively as a stormwater control device in an urban environment, the whole community needs to install rainwater tanks.

6 INSTALLATION ISSUES

One of the rising issues in an urban environment is space. With in-fill housing and subdivision of properties become more prevalent, the available space per property is becoming less and less. A 5,000-litre rainwater tank can have a diameter up to 2.5 metres or a height of around 2.5 metres for a tank of lesser diameter. Other options are to bury tanks or to install them under decks or alongside walls in thin tanks made for this purpose.

Many sections are now being sold with areas of less than 500m^2. The photographs below show a house with a 420m^2 section in South Auckland. The options for retrofitting a rainwater tank are very limited for a number of reasons:

- There is nowhere on the property where a circular tank could be installed (except for perhaps the location of the children's jungle gym).
- The house is already constructed and therefore the installation of a tank under the deck would require the deck to be demolished prior to installation and rebuilt afterwards.
- The access is severely limited to the property and digging a hole large enough to install a buried tank would be difficult.
- Installation of a tank under the eaves of the house along one wall would cover windows and significantly reduce the natural light in the house.
- The piping of all down pipes into the rainwater tank is extremely difficult and would require serious modifications to the household spouting.
- Visible tanks are ugly and the home owner may not want the eyesore.

Figure 8 Possible Rainwater Tank Locations

7 LEGAL ISSUES

One of the major issues in retrofitting rainwater tanks to existing properties is sections 9 and 10 of the Resource Management Act. These sections ensure that any activity which is permitted under one set of rules cannot be changed by a subsequent set of rules. Therefore it would be extremely difficult legally to impose the installation of rainwater tanks on existing households. It is possible to impose the installation of rainwater tanks on properties where a significant change to the property is occurring providing the rule is detailed in the relevant district plan.

8 CONCLUSIONS

The decision to install rainwater tanks in an urban area to supplement a reticulated network must be made on a case by case basis. For each case, the following aspects should be considered as a minimum:

- The actual rainfall in the area considered.
- The actual demand per household – this can be further refined from a simple average annual daily usage to an average summer daily and average winter daily usage if required.
- The average roof area in the urban area.
- The potential cost impacts of rainwater tank installation.
- The potential environmental benefits of rainwater tank installation as a stormwater attenuation and quality management system
- The potential to delay major infrastructure spending
- The practicality of retrofitting rainwater tanks of sufficient size to existing properties.
- Any water quality issues resulting in longer network residence times.

Simple modeling of a system will demonstrate whether rainwater tanks will be able to sustain a year round supply in the local area. To date all modeling of supplementary rainwater tanks for toilet flushing and outside usage only, has shown that during dry periods the tanks run dry. Therefore for the purposes of water supply planning in terms of treatment and reticulation, rainwater tanks must be assumed not to exist. However, in terms of residence time in the reticulated network, rainwater tanks may have a negative effect. Further, where the water source is not stored water, rainwater tanks offer no benefit in terms of reducing the load on the resource. When the river flows are low, the rainwater tanks are empty.

The installation of rainwater tanks cannot be viewed as a cost reduction exercise. The cost of installation far outweighs any savings in the water used. Indeed, if rainwater tanks were installed throughout a water supply area, the unit cost of water would increase significantly.

The location of rainwater tanks must be considered on a property by property basis and retrofitting may be difficult. To enforce the installation of rainwater tanks into an existing urban environment is almost impossible due to sections 9 and 10 of the Resource Management Act.

The blanket statement that, "rainwater tanks are sustainable" is clearly not true. If the definition of sustainability is that defined in the Local Government Act, then each case must be weighed on an environmental, economic, social and cultural basis. Further it is dangerous to assume that just because it is assumed to be sustainable, it is sustainable. Rainwater tanks should not be sold as a blanket sustainable solution but careful analysis of each individual supply should be undertaken before the sustainability label is applied.

From studies carried out to date by the author on the use of rainwater tanks in the urban environment, no system has proved sufficiently attractive to mandate the use of rainwater tanks.

Rainwater tanks in the urban environment – friend or foe? The correct answer may be "false friend".

ACKNOWLEDGEMENTS

Andrew Venmore – Whangarei District Council

Bruce Fulford – Rodney District Council

Santha Gunasantha – Whakatane District Council

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