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# Rain water harvesting in urban New Zealand

## Master's Project


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# Abstract

Rainwater harvesting is a practice already widely used throughout rural New-Zealand, which makes it well developed on the country's market as well as in people's minds. Therefore, it is pertinent to study whether this sustainable practice could be implemented in urban areas so as to provide water for purposes such as toilet flushing, washing machines and garden use. This study concentrates on the health issues posed by roof water collecting with qualitative results for water quality, and on other aspects such as costs and benefits of such systems, politics towards this practice, and the impact it can have in recovering from a natural disaster. The results showed both environmental and faecal contamination of the harvested rainwater especially after important rainfall events, and the presence of such contamination in stored water can lead to disease outbreaks especially if consumed. However, testing effectuated on first flush diverted volumes revealed that such devices can considerably improve the harvested water's quality if a quantity of water between fifty and eighty litres is diverted at the beginning of heavy rainfall. Cost wise, the slimline tanks series is well adapted to urban environments due to their shape but the price to pay is twice that of a normal tank. A 5'000 litres normal tank seems the best option as its mean price is of 1'500 NZD and its efficiency in providing the household with water for different uses is usually around 80% and can reach up to 95%. Furthermore, if in the future the authorities realize the advantages of having rainwater tanks installed in urban areas, rebates could then be offered on the acquirement of such systems.

# Introduction: Roof-collected rainwater harvesting

New Zealand appears to have plenty of fresh water but climatic and hydrological extremes and the resulting unpredictable distribution of water, challenges the management of this resource. In rural and semi-urban regions of New Zealand, rainwater harvesting is already wide-spread, with around 400'000 people depending on it in areas that are not served by municipal town supplies. This represents 10% of the country's population, and the number should continue to increase since more local authorities are encouraging that practice by offering rebates to those who install tanks in new or existing households, so as to relieve the mains water demand and also because it helps to reduce storm water runoff. This awareness might evolve to the point where building consents are delivered only if the installation of a rainwater tank is planned, like it is already the case in some localities in Australia.

On a legal base, the health Act states that it is illegal to sell a house unless it is equipped with a supply of potable water. An individual household drinking water supply (serves less than 1'500 person days) isn't required to meet with the Drinking Water Standards for New Zealand (DWSNZ 2005), but it still has to respect the maximum acceptable values. These MAVs are in the case of E-coli or total coliform of less than one organism per 100mL. A lot of research has been conducted on the quality of roof-collected rainwater by testing samples, and it appears that most of the rainwater tanks tested is contaminated (Krishna, 1989; Wirojanagud *et al.* 1989; Fujioka *et al.* 1991). The Roof Water Research Centre has led a five years study on the microbiological quality of roof-collected rainwater in private dwellings from different parts of New Zealand, and the results are alarming: more than half are contaminated and 30% show heavy faecal contamination (Abbott *et al.* 2006).

These contaminations result mainly from inappropriate use and maintenance of the components (tank, roof catchment, pipes…) by users, and the risk it creates can be considerably reduced by the use of well-designed tanks associated with a regular maintenance. The better the system has been designed and the less it will need maintenance, and it is accepted that if a tank's design and maintenance are appropriate, the need for water disinfection with chlorine or other chemicals is minimal (Gould 1999, Gould & Nissen-Petersen, 1999). One component that should be included in every roof-collected rainwater tank is the first flush diverter, which is very efficient in removing faeces as well as dust, ashes, heavy metals and chemical residues after long dry periods during which it has accumulated on roofs (Abbott *et al.* 2007). It diverts the first 'dirty' water that pours down the pipe (2mm of rainfall should be diverted for good results) and only lets the cleaner water in the tank. This item has its importance in urban areas especially as there are more polluted air particles, and potentially more birds staying on the roofs. Faecal contamination can also simply be prevented with the use of plane roofs without overhanging trees, as well as the use of gutter meshes and filters. Furthermore, tanks need to be regularly desludged, cleaned and replenished with water respecting the DWSNZ.

The consumption of contaminated tank rainwater induces an increased risk of gastrointestinal illness and is related to a number of other waterborne diseases. Unfortunately, there is a massive underreporting of illnesses associated with contaminated roof-water because these kinds of systems serve individual households. This creates sporadic disease episodes in which people don't usually go to doctors (Wheeler *et al.* 1999). Since the majority of waterborne diseases arise outside of large outbreaks, most of them are not reported and documented. Therefore there is an important need for a better communication and awareness from health specialists and local authorities in order to change people's behavior towards rainwater harvesting. However, this process can only be successful if it requires low investment to the users, and if the need for change is based on sound evidence.

The harvesting of rainwater is also applied to urban areas, as it is attested by the Auckland Hospital which uses it for flushing its 530 toilets. With over 700 staff and a capacity for 570 beds, so an average of constantly around 1'500 people per day (with interns and visitors) the hospital saves around 20'000L of potable water per day, which on the actual Auckland City water fares represents more than 13'000$ per year and will probably rise in the future.

# 1. Rainwater tanks

## 1.1 Tank types

The rainwater tanks industry is in constant evolution, and its development has brought new tank designs on the market in order to comply with aesthetic needs of the clients. The basic tanks, in steel or polyethylene are still very common, but underground tanks, bladders and slimline tanks are invading the market.

Figure 1: Plastic rainwater tank

- The most spread tanks are basic and stand on the ground close enough to the house to receive easily the water harvested on the roof. They have first appeared in corrugated galvanized steel, an option that was widely used in the South of Australia to the point of becoming a national icon there. They are now also manufactured in polyethylene, easy to mould, light for transport and available in a large choice of colors. Concrete rainwater tanks are also used in this kind of configuration but are more difficult to install and suit better underground use. This type of tanks has the advantages of being cheap and very easy to install, but pose an obvious problem of aesthetic by standing close to houses while hiding them with vegetation is not recommended since it would increase the risk of animal contamination on the roof.

- Slimline tanks and their compact design are a very good option to avoid the problems of aesthetic and space caused by basic tanks. They can come in poly, steel and stainless steel in a large range of shapes and colors in order to adapt to any house and needs of the user. They are usually placed against walls or fences, and generally range from 600 to 5'200L.

Figure 2: Slimline tank

- Bladder water tanks can also be very handy in some cases since their shape permits them to fit in places inaccessible by other hard tanks: under deckings, in caves, under a veranda… They are also interesting in their prices, and can offer a very wide range of volumes to pick from: on the market you can find bladders between 1'000 and 11'000L for private use, up to 70'000L for industrial use, and in some special cases bladder tanks with a capacity of a million litres have been created and used successfully.

Figure 3: Bladder tank under a deck

- In the case of newly built houses, underground concrete tanks are a prime option because they can be easily installed during the construction phase and will not pose the least problem of space or aesthetic. The space saved can therefore be used for any other purposes. They have different advantages, like being long-lasting, being in a colder and sunlight proof environment which reduces algae and bacteria growth, and they range from 700 to 10'000L. Underground tanks can also be made of fiberglass and polyethylene, the latter becoming increasingly common nowadays. A pump is always required for this kind of water storage to get the rainwater back up in the house.

Figure 4: Underground tank

- Tanks of way bigger proportions are also used in some cases, especially in schools, sport centers and for industry or agriculture. They are made of concrete or Zincalume with Colourbound steel, and can have a capacity up to 770’000L. These tanks can be linked to roofs for rainwater harvesting, but in other cases they are used just for water storage. Some of these could still be involved in rainwater collection by including gutters to the tank’s roof so as to collect the rainfall over the surface of the tank (Rhino Tank). This surface can be very important, over 200 square meters for the tanks over 500’000 litres. In the case of concrete tanks, when the water is slightly acidic it can leach calcium from the concrete into the water and therefore the use of a polyethylene liner is recommended. However, this type of rainwater harvesting tank does not fit and is not required in an urban area except for purposes such as water storage for municipal services (street cleaning, parks and gardens watering…). Otherwise, it can’t be applied to a household in any urban environment.

Figure 5: rhinotanks.co.nz

## 1.2 Detention tanks

Rainwater tanks can have multiple purposes: the most usual are retention tanks with all of the harvested rainwater saved for domestic use, but detention of stormwater is sometimes required by a number of councils depending on the size of the dwelling and in this case detention tanks are an existing option, as well as multipurpose tanks with both retention and detention capacities.

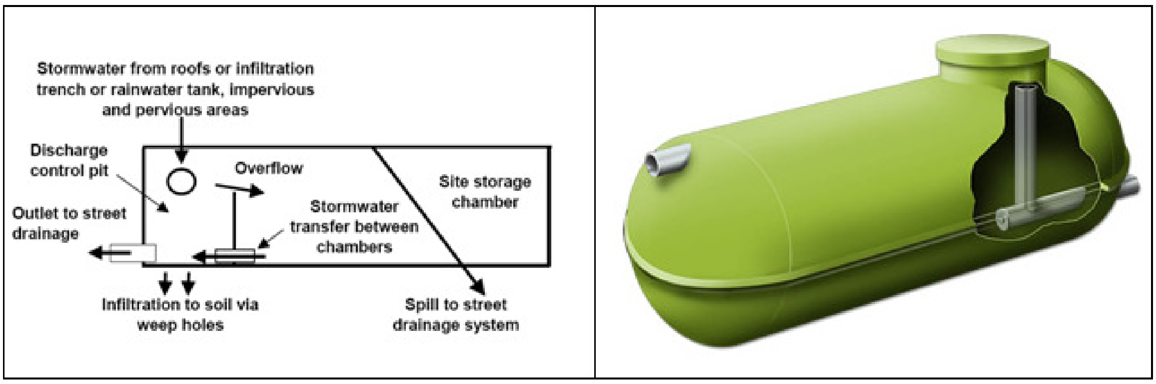


Figure 6: On-site Stormwater Detention Tank

With the multiplication of constructed ground, larger hard surfaces increases the pressure on the draining infrastructure in major rain events, along with problems of flooding and soil erosion. In order to reduce the quantity of runoff water, different detention structures exist such as planter boxes, porous pavement, infiltration trenches and closer to our topic ecoroofs. But one very common detention technique applicable to every dwelling that is required to do it is On-site Stormwater Detention tanks. After being collected from the roof, the rainwater is directed into the detention tank where it is stored and then slowly emptied in a controlled manner by the size of the outlet orifice which determines the outflow. The stronger and the longer the rainfall event is the larger the tank capacity should be otherwise there is increased spillage that goes on straight to the draining system. Detention can be incorporated in a retention tank by separating the storage volume in two parts: the lower one for domestic use with an outflow only when needed, and the upper one used for stormwater detention and filled only during a major rainfall, water which is then slowly and automatically evacuated to draining infrastructures with an orifice controlled outlet. The use of rainwater detention tanks on a large scale can be cost-effective for reducing stormwater runoff compared to other constructed systems such as detention basins.

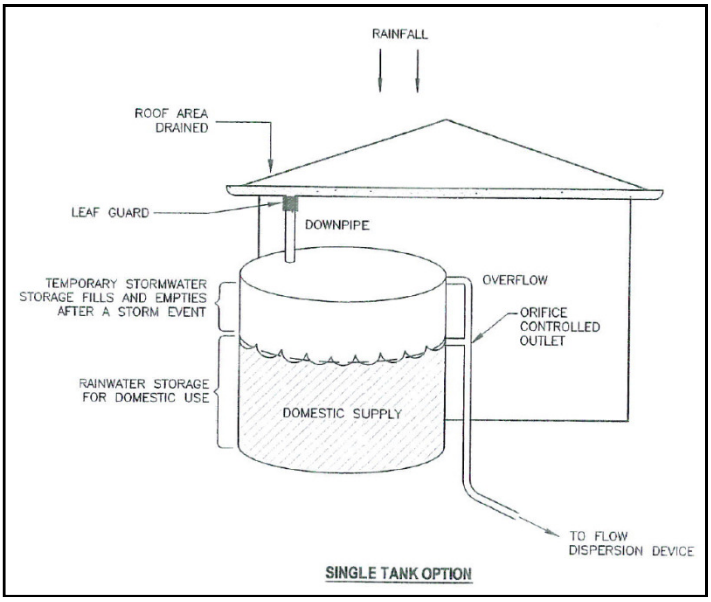


**Figure 7: Retention + Detention Tank**

The general trend tends towards authorities requiring more and more that newly built houses in some areas be equipped by such detention or retention tanks, as it is already the case in places in Australia. The Campbelltown City Council is an example with a required 2’000 litres of stormwater from the roof detention for each dwelling on allotment less than 500 squared metres (Campbelltown City Council, 2006). And today the Greater Auckland local authorities are increasingly insisting on the installation of stormwater detention devices for all new houses so as to control the flow of runoff.

## 1.3 Rainwater tanks placement

Rainwater tanks can be placed underground or aboveground, with some of them being only partially buried. When underground, they offer the advantage of being invisible to the eye. However, an important issue especially with concrete tanks is that water may after a certain time be able to leak through the wall, which is problematic due to possible contamination by groundwater or floodwater and can be dangerous in the case of the proximity of a septic tank, a heavy source of fecal contamination. Therefore, underground tanks should not be placed at a depth inferior to the maximum water table rise. Such problems are fought by modern tanks with better material as well as with the use of a liner inside the tank, but must be kept in mind during the installation. On the other hand, the pollution that can enter the tank from the roof via the downpipes is less likely to develop in an underground tank thanks to the low temperature and to the complete absence of sunlight exposition. Underground tanks can be placed about anywhere as long as the vertical pressure respects the tanks notice: Some may withstand the weight of a parked car, whereas it can be damageable to others, especially if in polyethylene. Still, thanks to the partial support of ground less material is needed to support water pressure in the case of buried tanks. Also, the length of the pipes should be shortened to the maximum in order to reduce problems linked to them (leakage, puncture during works) and therefore be placed close enough to the house. Since the rainwater tank is situated below the level of the dwelling, the use of a pump is necessary to carry the water to garden hoses as well as to toilets and washing machines.

A pumping system is not always required in the case of aboveground rainwater tanks. They can be placed on higher structures, so that the lid is almost leveled with the gutters and therefore the lower level of the habitation and the garden can be served using sole gravity. This is especially efficient in the event of power shortages in the vicinity. Generally, tanks should be placed on pads so as to prevent them from sinking in the ground, especially when the tank has a full capacity of 5000L or more. This time again in order to reduce the length of pipes used the tank must be placed as close to the roof as possible. In the case of Slimline tanks the better option is obviously to install them against the walls of the house, but other walls or fences can also be used. Bladder tanks as for them can easily fit under a deck or in a cave and a pump will be necessary to carry the collected rainwater upstairs for its use. An advantage of above ground tanks over the underground ones is that they allow for easy inspection of cracks and leakage.

## 1.4 Tank materials

Tanks are today available in a vast variety of forms, placement and also materials. The most spread rainwater tank materials are galvanized steel, fiberglass, concrete and plastic, and all have advantages as well as disadvantages. The right tank for a given dwelling will then depend on different factors, such as the financing, the available space that can be occupied by the tank, the quantity of required collected water, the expected lifespan of the tank and the level of water quality and taste wanted. Here is an overview of the different tank materials and their specificities:

- Galvanized steel used to be the most common material in the manufacture of rainwater tanks, and is also usually the cheapest on the market. Steel is not resistant to corrosion but initial corrosion leads to the production of a thin coating on the interior surface which protects it against further corrosion. Otherwise, it is possible to use rust-resistant coatings such as Zincalume® or Aquaplate® which give a better protection against corrosion and lead to a lifetime of over 20 years, or plastic liners. Another easy way to extend the lifetime of a steel tank is by placing anodes inside the tank that will corrode in place of anodic areas of the steel surface, or by using a limestone as a way to reduce the acidity of the stored rainwater. When new, this type of tanks may leach excess zinc in the rainwater therefore altering its taste but not its health risk.

- Concrete and ferro-cement tanks are widely used in high-income countries and can be transported by truck from the factory and installed with a crane, or brought on-site in panels and then assembled since it is a very heavy material. Over time, concrete might leach lime and give slightly alkaline water, and it can also be penetrated by the water which may cause corrosion of the steel framework. These problems can however be easily avoided by the use of a plastic liner inside the tank. Concrete allows for tanks to be either above or underground and offer in both cases a strong resistance to outside elements, including pressure, impacts or fires.

- Plastic is used in increasing proportions for tanks manufacturing, making it the fastest growing on the market in high-income countries especially thanks to its competitive prices. The materials used are synthetic polymers and above all polyethylene; they must be at least of food-grade standard and preferably comply with the requirements of AS/NZS4020. This type of tanks offers lighter products that are easy to install, can come in underground versions, but that are also more fragile and subject to external pressure. Fortunately, the technology surrounding plastic tanks is in constant evolution and most manufacturers can propose strong and long-lasting products. The fact that these tanks are molded allows for a very large variety of shapes, and they can easily be made compatible to new pipe/cleaning/vacuum systems. Inconvenient created by the use of plastic are the taste it can give to the water on days with an extremely high outside air temperature, as well as limited knowledge we have on the long-term effects of drinking water stored in this material as it is relatively new in the market.

- Fiberglass rainwater tanks are also quite popular, and have many advantages such as their resistance to rust and chemical corrosion, as well as their ability to withstand extreme temperatures. But on the other side this kind of tanks tends to be brittle so prone to cracks and this has damageable consequences especially if placed underground. When above ground, fiberglass is not lightproof and therefore the tanks may encourage algal growth if they are not painted beforehand.

- Other rainwater storing tanks materials include bricks (in developing countries) or wood with an inside plastic liner, but these are not present on the market today.

As much as rainwater tanks materials are important to take in consideration, roofing, guttering, down-pipes and pipe work can also alter the quality of the harvested rainwater. Rainwater itself is of very good quality, but once it has hit the roof it can collect pollution or dust that has landed there during the dry period, or by leaching and dissolving of the material the roof is made of. Specifically, the roof material used should be as smooth as possible so as to prevent deposition of dust, leaves, bird-droppings and other debris, as well as the proliferation of plants and insects (Farreny *et al, 2011)*. Iron, fiberglass or membrane roofing is therefore preferable to tiles or asphalt. In regard to faecal contamination, metal roofs can give better results as they have low emissivity so higher temperatures to keep away birds and rodents, high temperatures that may also have a sterilizing effect. Lead must not be used for roof flashing or gutter solders as it can dissolve with the slightly acidic rain and contaminate the collected water. Wooden shingles are also not recommended, since they favor the development of mold and fungus, giving high DOC concentrations that mean high concentrations of disinfection byproducts. Furthermore, like with some other roof materials wood shingles are painted or treated with chemicals unfit for human consumption. Otherwise there is no perfect roof material, but it is very important to maintain and treat it with care without using substances or coatings that prove to be unhealthy for human consumption. Gutters and down-pipes are generally made of seamless extruded aluminium, galvanized steel or PVC, the latter being increasingly common especially for pipework and pipe connections. What needs to be checked before harvesting rainwater is that all roofing, guttering, down-pipes and pipe work must comply with ***AS/NZS 4020 – Testing of products for use in contact with drinking water***.

General products used must comply with Australian and Australian/New Zealand Standards that apply to tanks and their associated fixtures and fittings, such as:

- AS 2070 Plastics materials for food contact use
- AS/NZS 2179 Specifications for rainwater goods, accessories and fasteners
- AS 2180 Metal rainwater goods – selection and installation
- AS/NZS 3500 National plumbing and drainage code
- AS/NZS 4020 Testing of products for use in contact with drinking water
- AS/NZS 4130 Polyethylene (PE) pipes for pressure applications.

Generally and for the study in particular polyethylene tanks and guttering and pipe systems will be chosen as they are the most spread out and they represent a vast majority of the market today.

# 2. Rural and Health Risk

## 2.1 Health Risks of Roof-Collected Rain Water

In rural New Zealand, the perception is that rainwater is "pure" whereas municipal water contains too many harmful chemicals, especially chlorine which alters its taste (Abbott, 2008). But insufficient roof and catchment cleaning, and tank maintenance lead to contamination of that rainwater via growth of bacteria. This growth is enhanced in warm conditions and with the presence of sufficient nutriments in the tank, like algae or rotting vegetation. The source of contamination is in majority faeces from birds and small animals (frogs, rodents, cats...) and there are several ways of reducing the number of bacteria in the tank. First of all the tank needs to be completely light-proof so as to prevent bacterial growth, and these also suffer natural die-off because of the temperature, nutrient concentrations that may be too low, salinity, pH, presence of toxic agents or predation and parasitism. It is also possible to treat the water, with on-site chlorination, filtration, boiling it, or solar disinfection (SODIS) and UV sterilization, treatments which remove part or all of the bacteria. The worst quality of roof-collected rainwater in a tank is just after major rainfall events, and then it recedes with time as rainwater cisterns have a self-disinfection action.

Airborne microorganisms end up on roof as well, and this is why *E.coli* or faecal coliforms should be used as indicator bacteria for stored rainwater as they have animal or human origin only. Maximum Acceptable Values for faecal coliforms in potable water is less than 1 per 100ml, but a more reasonable classification can be issued considering that zero contamination is hard to attain. This is a possible classification for drinking standards (Krishna, 1993):

- 0 faecal coliforms per 100 ml → ideal water
- 1 to 10 faecal coliforms per 100 ml → acceptable risk
- Over 10 faecal coliforms per 100 ml → unacceptable for drinking

In different studies conducted in New Zealand, Australia and Tasmania, a great percentage of samples are non-compliant while some have a very high contamination (sometimes over 500 *E.coli* per 100ml). Other bacterial pathogens such as *Salmonella* spp. and *Campylobacter* spp. are found in tanks and can be the origin of waterborne disease outbreaks (Lye, 2002; Simmons *et al.* 2008). One major problem is that contaminated tanks often remain so because roof-collected rainwater supplies serving less than 25 people in New Zealand are classified as unregistered supplies and therefore not monitored regularly. Research is now ongoing to find better ways to assess the microbiological quality of drinking water than using indicators such as coliforms, including new detection methodologies such as molecular techniques. Also, the health risks associated with non-compliant roof-collected rainwater consumption are not well defined or quantified today, and rely on many factors; an example is the minimum infective dose that depends on the susceptibility of the host (child, adult, healthy...?). Simmons *et al.* (2001) have proposed the following method for Microbial Risk Assessment of health impacts:

- Hazard identification (what birds/animals? What pathogens? At risk populations?)
- Exposure assessment
- Dose-response (Infective dose, rate of infection, immunity...)
- Risk characterizations

Figure 8: Private dwelling in Waitarere

## 2.2 Survey of microbiological quality of roof-collected rainwater in private dwellings NZ

A five years long study was led by the Roof Water Research Centre on samples from 560 different private dwellings so as to study their water's quality. Each sample was first checked for the presence of total coliforms, and in the case of a positive result a further test for E-coli presence was conducted. It appeared that 70% of the samples didn't comply with the DWSNZ 2005 standards, which don't allow for the presence of any coliforms per 100ml. Also, 30% of the tested dwellings showed heavy faecal contamination, due to bad maintenance of the rainwater harvesting system. Whatsoever, it was revealed that there is no correlation between the presence of environmental and faecal contamination. The presence of E.coli mostly came with a more or less important presence of total coliforms, but a number of samples showed a very heavy environmental contamination without the slightest trace of E.coli. It is also important to note that total coliforms and E.Coli are very good indicators for respectively environmental and faecal contamination, but as indicators if they are found in low levels it does not necessarily indicate an absence of viruses and protozoa. However, to make the control safe, it is thought that positive total coliform result must be treated as though it were a positive E.Coli result. This is a precautionary measure but as it has been observed the contamination of a given tank can vary greatly through time and the absence of faecal contamination along with low environmental at the time of sampling does not always mean that the water stored in the tank is more or less safe to drink. In order to treat the water, as prevention or as a response to existing contamination, different techniques improve the bacteriological quality of supplies, such as chlorination, filtration or UV light treatment among others (Rutter *et al.* 2000). Another means of prevention proposed was the creation of a roof-collected rainwater risk management system similar to those used today for swimming in recreational areas such as beaches and parts of lakes. This would rank the different levels of contamination with an easy colour grade and make it easier for people to understand and evaluate the risks they are taking.

## 2.3 Sampling

In order to get an overview of the water quality of water (potable and non-potable) in rural New Zealand, a sampling trip was done to Waitarere Breach, a small seasonal town situated on the coast of the Tasman Sea on the Southwest of the Northern Island. Waiterere Beach is not connected to mains water supply even though this may happen in the future, therefore its inhabitants rely either on bore water or rainwater, or both. Overall fourteen water samples were taken from twelve different households from kitchen taps or outside taps. Out of these fourteen samples, nine were bore water samples and the five remaining were tank rainwater samples (see annex 1 for results).

Neither of the nine bore water samples showed faecal contamination; however two of them taken at the same house showed very heavy environmental contamination, even at the kitchen tap. The tank water samples results showed a water of worse quality: all samples showed heavy to very heavy environmental contamination, and there was faecal contamination of four out of the five samples as well. Also, out of these five tank water tested, three are used for the kitchen tap.

These results emphasize the problem of water quality that can be posed by rainwater collection if the right measures are not undertaken to treat it and keep it clean. Unlike bore water, tank water can undergo faecal contamination mainly due to excrement deposited on roofs by birds and small rodents, and this can lead to diseases by the consumer. This relatively bad water quality is symptomatic of rural areas, and regular inhabitants don't mind it as their organisms get use to drinking that water. But in the case of Oceanside towns like Waitarere where the population doubles in the summer when tourists come over, these people are not used to drinking contaminated water and this can lead to an increase of waterbourne related diseases. This sampling campaign shows clearly the challenge of using harvested rainwater as a water supply.

# 3. Rainwater Harvesting in Urban Environments

The aim being to implement the use of rainwater tanks in urban environments, it is important to look closer to the feasibility of legally installing such a system in a household. Usually cross-connection of the rainwater tank's plumbing to the mains water supply is only permitted if back-flow prevention devices are installed so as to prevent the possibility of water from the rain water tank entering the mains supply infrastructure which could prove dangerous for a whole community if the tank water was heavily contaminated. However, some local authority regulations expressly forbid the connection of rainwater tanks to the drinking water supply if mains water is available, but do allow separate connections for other indoor uses such as using the rainwater to flush toilets. This requires doubling the plumbing in the household and can get expensive to install but does guarantee a perfect independence of the two water supplies and avoid the network contamination problems mentioned above. Also, if the water is supplied to the bathroom or kitchen through the hot water system only, then these concerns may be ameliorated because most pathogenic bacteria can be eliminated at high temperatures. On another level, the requirements for the inclusion of treatment devices in the rainwater supply depend on the local authorities, as some have no compliance requirements whereas others have very strict and specific requirements for the cleaning, storage and disinfection of roof-collected rainwater.

The amount of rainfall run-off that can be captured depends on different factors such as the size of the roof used for harvesting, the local rainfall, the size of the tank but also the condition of the gutters which can create spilling and losses ranging from 10% to 40% in the worst cases. Therefore there is only a certain amount of water available and it varies through time and can't always meet demand. This demand also varies, depending on the number of people in the household, the time of the year and to an important extent what the harvested rainwater will be used for.

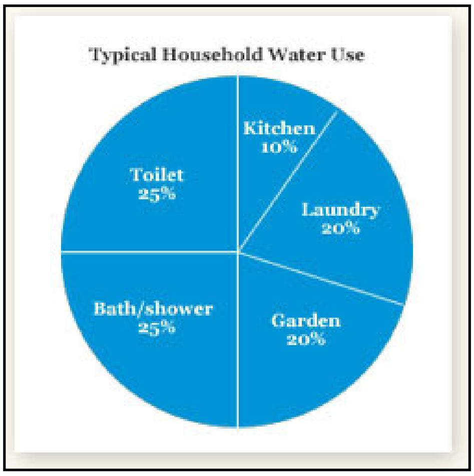


Figure 9: Typical New Zealand household use

This figure shows an evaluation of a typical New Zealand household use, which gives 65% of the daily water use either for toilet flushing, laundry or outdoor use and could therefore be tank collected rainwater. These numbers differ a bit from other accepted values, but still they put forward that without facing health risk, it is possible to save two thirds of the water actually used by replacing it with rainwater which is free once the tank is installed, sustainable and a resilient source of water. The 35% remaining which are water used for the kitchen and bath or shower can remain connected to the mains water supply.

And there are actually cases where rainwater can be used as drinking water in urban environments under some conditions: the Waitakere City Council in Auckland allows it as long as filters are installed and water quality is tested every six months. In that same council no building consent is needed to use harvested rainwater for garden use, nut it is the case if this water is connected to the plumbing in order to aliment the laundry or the toilets.

So for use in laundry, toilets and garden, the connection to the rainwater tank is feasible and can save a lot of water. Other important issue are the size of the tank which can be a limiting factor due to the absence of room in towns, the cost which can be a setback to many households and the water quality. In order to get an idea on the actual feasibility of the development of tanks in urban areas and the efficiency they would have, all these topics were explored in this study.

## 3.1 Sampling of urban tanks

As part of the study, rainwater collected from tanks in urban areas has been sampled as well in order to see how these already existing tanks behave under different user's conditions.

A 25'000 litres tank was sampled in Brooklyn, Wellington where it is stored under a deck and is not currently used, be it for drinking water or just for watering the garden that surrounds it. Its owner built the tank for emergency use for his household as well as his neighbor's in case of water cutoff (natural disasters or extended drought), and hopes for the city council to realize one day the advantage of home tanks and offer him a rebate on the price he originally paid for the system. Three samples were taken, one at the top, one at the middle and one at the bottom, and the results for those three samples showed very heavy environmental contamination, and slight faecal contamination but only in the middle sample. This water was not treated in any way, but can be used in emergencies if it is boiled and could be used in the household on a regular basis if treatment was planned as well as a good maintenance of the tank.

A tank with a capacity of 10'000L and used for gardening and in case of emergency was sampled in Karori, Wellington. The water sampled showed less environmental contamination than the last tank but could still be ranked as heavily contaminated at the time of sampling, and it also showed slight faecal contamination. These results are far from the drinking standards, but the water from this rainwater collecting tank isn't treated on a regular basis and therefore its quality can be greatly improved by using simple treatment and maintenance measures.

Other samples were sent to us from Nelson (North of New Zealand's South Island), from rainwater harvesting tanks also situated in semi-urban environments and used as water supply for the whole household. The samples were taken at the kitchen tap and sent in a chilly bin to the Roof Water Research Centre in Wellington which took one day on average, and therefore the temperature of the samples was taken on arrival to make sure they were not too warm which could have helped bacteria developing and enhanced contamination. The first sample to come in showed very slight environmental and faecal contamination after testing, which gives a good water quality and shows that if the right measures are taken it is possible to obtain drinkable harvested rainwater in urban environments. This harvested rainwater was in fact filtered through a 0.5 micron carbon activated silver impregnated filter that generally is very efficient in removing impurities. However, the next sample from harvested roof water was untreated before getting to the kitchen tap and the results for the water's quality showed environmental contamination but no faecal contamination, which were better results than those from samples issued by spring water use in the same area who all showed both environmental and faecal contamination (see results in annex 2).

## 4. Sampling the RWRC tanks

On a more regular basis, tanks from the Roof Water Research Centre at Massey University were sampled seven times. All the tanks are supplied with rainwater harvested by a 300 $m^2$ roof, transported through gutters to a smaller 30 $m^2$ that also harvests rainwater, and all the water that ends up on that roof is then brought to a gutter with two catchments leading to the different tanks. Three of these RWRC tanks are currently equipped with first flush diverters of different sizes. Samples from these tanks and diverters were taken regularly after rainfall events, in order to get an idea of the quality of the harvested rainwater as well as of what an ideal size would be for a first flush diverter. Ten samples came from different levels of filling of a 120L first flush diverter (bottles B1A to B5B), two from tank 5 with a capacity of 5'000L which is connected to this first flush diverter (one at the top, one at the bottom), two from 1'000L tank 7 equipped with a 25L first flush diverter (top and bottom), two from 1'000L tank 8 equipped with a 15L first flush diverter (top and bottom) and two from 5'000L tank 6 which is the control tank with no diverter (top and bottom). The sampling was done approximately every week when all the bottles were full after sufficient rain events. The rainfall history on the period of time the sampling lasted was also monitored so as to be able to compare it with the results.

The samples were all tested for total coliforms and *E-coli* with the Colilert method, in order to get a range of both environmental and faecal contamination. This technique uses Defined Substrate Technology® nutrient indicators to detect coliforms and *E-coli*. ONBG is metabolized by the β-galctosidase of coliforms and changes from colorless to yellow, while MUG is metabolized by the β-glucuronidase of *E-coli* and creates fluorescence. After 24h incubation at 36.5°C, results are read by counting numbers of colored/fluorescent large and small wells and then used to calculate the MPN with the IDEXX MPN generator 3.2. UV light is required to record the number of wells subject to faecal contamination. This technique is faster and easier to use than membrane filtration, and as it leaves less room for error (the MPN comes along with a 95% confidence limit) it has become the standard technique for water quality testing in Australia and New Zealand.

As an example, the two first sets of measures are given in the following tables, while the whole results are in annex 3. These first two sets are very representative as they show the two types of results obtained generally throughout the study: good results after light rainfall, and contamination sometimes heavy after heavy rainfall events.

**Table 1: RWRC sampling results**

| Sample 1 – 31/03/2011 | | | Sample 2 – 06/04/2011 | | |
|---|---|---|---|---|---|
| Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) | Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
| B1 A | 3.0 | 0.0 | B1 A | 0.0 | 0.0 |
| B1 B | 0.0 | 0.0 | B1 B | 0.0 | 0.0 |
| B2 A | 0.0 | 0.0 | B2 A | 4.1 | 0.0 |
| B2 B | 0.0 | 0.0 | B2 B | 2.0 | 0.0 |
| B3 A | 0.0 | 0.0 | B3 A | 1.0 | 0.0 |
| B3 B | 0.0 | 0.0 | B3 B | 290.9 | 19.5 |
| B4 A | 0.0 | 0.0 | B4 A | 65.0 | 2.0 |
| B4 B | 0.0 | 0.0 | B4 B | 6.3 | 0.0 |
| B5 A | - | - | B5 A | 12.1 | 1.0 |
| B5 B | - | - | B5 B | 7.4 | 3.0 |
| | | | | | |
| T5 A | 0.0 | 0.0 | T5 A | 0.0 | 0.0 |
| T5 D | 0.0 | 0.0 | T5 D | 2.0 | 0.0 |
| T6 A | 1.0 | 0.0 | T6 A | 25.9 | 3.1 |
| T6 D | 3.0 | 0.0 | T6 D | 35.0 | 5.2 |
| T7 A | 7.5 | 0.0 | T7 A | 125.9 | 7.5 |
| T7 B | 7.4 | 0.0 | T7 B | 101.4 | 9.8 |
| T8 A | 0.0 | 0.0 | T8 A | 0.0 | 0.0 |
| T8 B | 0.0 | 0.0 | T8 B | 0.0 | 0.0 |

1. The first two sets of results showed very different results. The first sampling was done after a relatively dry period interrupted by rather small rainfall events. On the tank 5's first flush diverter, it appears that only the first 2L of runoff from the roof showed slight signs of environmental pollution, whereas the rainwater that filled it afterwards was clean, and so was the water inside the tank 5. Tank 6 with no attached device and tank 7 with 25L diverter showed slight traces of environmental pollution, and tank 8 with the 15L diverter proved to be clean.

2. The second sampling gives interesting results as it was done shortly after a very large rain event with up to 30mm of rain on one day (see figure below). The first liters of water that were diverted show only little contamination, until a huge peak hit at Bottle 3B onto Bottle 4A, which can probably be explained by a peak in the rainfall. After that, the water diverted gets of better quality, good enough to provide tank 5 with clear water, showing only slight contamination at the bottom. Control tank 6 showed better results than tank 7 which was heavily contaminated, whereas tank 8 samples were clean. Here again the tank with the smallest first flush diverter shows the best water quality which is definitely not what would be expected, and the tank with 25L first flush diverter seems to show that this capacity is not enough to divert all the contaminated water.

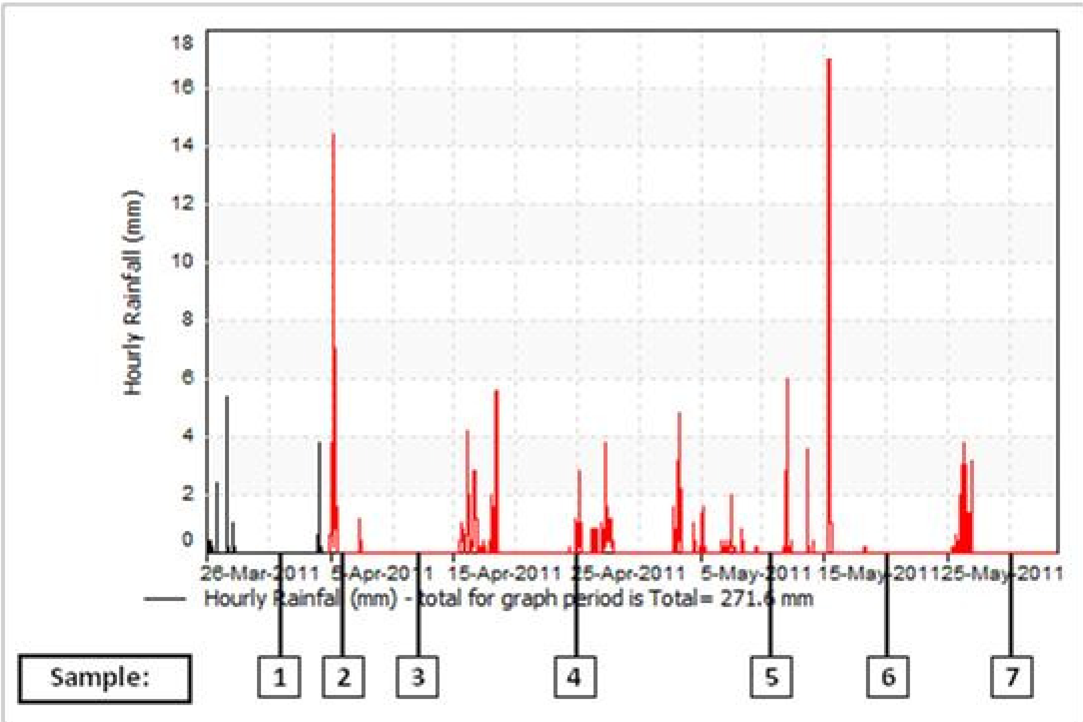


**Figure 10: Rainfall events in relation to sampling date**

3. The third set of sampling was done after a relatively dry period of time and therefore only four of the first flush diverter's bottles were full and could be sampled for testing. It appeared that all four bottles showed only slight environmental contamination and no trace of E.Coli, which was also the case for all tanks except tank seven which again showed total coliform counts higher than the rest and also some trace of faecal contamination.

4. The fourth set gave results similar to those obtained on the second sampling, with a first flush volume starting to appear contaminated starting from the third set of bottles, and then slowly increasing in quality, passing from 107.6 total coliforms per 100ml in bottle B3A to no total coliforms at all in both bottles B5A and B5B. The results obtained on the tanks 6 (control) and the 7 (25L first flush diverter) showed environmental contamination again after a relatively big rain event, with also some slight faecal contamination of tank 7. Both other tanks' samples showed good quality stored water.

5. Set five was taken after a long period of well spread medium intensity rainfall events. None of the water diverted by the 120L first flush diverter showed sign of neither environmental nor faecal contamination. Furthermore, all tanks showed good results for both environmental and faecal coliforms per 100ml except for tank 7 which again showed some heavy environmental contamination.

6. The sixth set of samples was taken after the Roof Water Research Centre was hit by the largest rainfall event of the study with 39mm of rain for the 15th of May only. The start of this major event seems to be correlated with a huge increase in first flush volume contamination between bottles B2A and B3A. After that, it seems the roof has been cleaned out and no more contamination is to be noted. Therefore, the water getting into tank 5 remains clean, whereas that from both tanks 6 and 7 again shows heavy environmental and faecal contamination. Tank 8, equipped with the 15L first flush diverter only shows signs of slight contamination.

7. The last set of measures was done 10 days later, marked by only two days of rain in a smaller proportion. The results obtained by the bottles connected to the first flush diverter showed no sign at all of contamination, and those from the tanks showed an increase in water quality compared to ten days before.

Figure 11: 120L first flush diverter

In order to analyze the results given by the 120L first flush diverter, it is important to explain precisely how it works. The structure works as any such device, with a large diverted volume and a drop by drop outflow at the bottom. The diameter is of 1.25mm, which gives a time to empty completely of about fifteen hours when rainfall has ceased. However, this particular device has five outflow pipes on its side connected to five times two bottles of 20 litres each. The first one is situated at the bottom of the diverter, while the three next are respectively at ¼, ½, and ¾ of its length and the fifth is connected all the way at the top. Therefore, if a rainfall event fills in the first six bottles and is followed by a dry period long enough to empty the first flush diverter, the next event will need to be sufficiently important so as to fill in the three quarters of the device and then start fill in the remaining bottles. The results then have to be read accordingly, and if there is a huge gap in water quality between two successive pairs of bottles the difference might be due to a dry period that allowed the device to divert a large amount of water at the start of the next rainfall event.

Also, before the first sample there was enough rain to fill the whole first flush diverter but because it was spread out over five days and there was no noticeable peak it was not enough to fill the top two bottles. The results of all these samplings showed that a really heavy rainfall is necessary in order to give heavy contamination of the diverted water. This happened on three occasions, with samples two, four and six which were the only sampling dates preceded by a day that saw between 20 and 40 mm. In these three sets of results, heavy contamination was every time spread over two or three bottles from different pairs, with total coliforms ranging from 6.3 to 547.5 per 100ml. This means that the first flush contaminated diverted volume ranged between 40 and 90 litres, with 30 litres being stored between two sets of bottles and if we take a minimum of 5 litres of contaminated water sufficient to give heavy contamination for the twenty litres bottle. For sample two, there was around fifty litres of heavy contaminated flushed volume followed by another hundred litres of slightly contaminated water. For sample four, there was some eighty litres of contaminated water due to heavy rainfall after which the quality improved significantly to reach drinking standards. For sample six, fifty litres of water were heavily contaminated after which the quality again improved to drinking water standards all the way to the top of the first flush diverter. However, for each of the samples done it appeared that not much flush volume was needed to divert all the faecal contamination (between ten and twenty litres).

Therefore, heavy contamination of the diverted rainwater occurred only during the heavy rainfall events and regards volumes between fifty and eighty litres. On the other hand, after lighter rainfall and especially on the samplings made after those mentioned higher the quality of the diverted water proved to be way better, and mostly adequate to drinking standards. In samples one, five and seven almost every single bottle showed results of no total coliforms and no faecal coliforms per 100ml. Therefore, it seems that major rainfall events are necessary to clean out the dirt that deposited on the roof catchments but this rain does also clean it out close to perfection, with some ten days required after that before dirt is flushed again.

The lags observed in the results for heavy contamination (when the peak hits after the first two pairs of bottles) is then explained by lighter rain filling the first bottles before heavy rain happens and is strong enough to wash off the dirt deposited on the roof.

The results observed for the tanks have been quite similar to those obtained on the 120L first flush diverter. Unsurprisingly, tank five has always given some excellent results thanks to the huge device to which it is connected. Water stored in this tank has always proved to be of good quality, every time being respectful of the DWSNZ 2005 standards or extremely close from it. Even for sample 2 which saw some contamination of every bottle tested all the way to the top of the diverter, Tank 5 gave some clean results which mean that the last of dirt from the roof was diverted in the last pair of bottles (B5A and B5B).

Connected to the same catchment on the gutter was the control tank 6, which gave the expected results as well. Samples from this tank were contaminated on the three sampling dates that followed heavy rainfall events and gave contaminated first flushed volumes. For sample two, there was environmental contamination and slight faecal contamination. For sample six, there was heavy environmental and faecal contamination. And finally, sample four showed signs of environmental contamination but no faecal contamination. These differences in the importance of the contamination (sample four having the lowest and sample six the highest contamination) correspond to those observed in the first flush diverter's bottles. On the four other sampling dates, there was only slight environmental contamination of tank six (1 to 3 total coliforms per 100mL) and no faecal contamination.

When there was contamination however, it appeared that the top part of the tank was more contaminated than the bottom part. This is explained by the fact that the harvested water inlets are at the top of the tanks' interiors for all four tanks (unlike with calmed inlets) so the contaminated water arrives at the top of the storage. There is discussion on whether the coliforms settle and how fast they do it, and from the results obtained not much settling has been observed as the main contaminated compartment is the top one. However, on the next samplings tested after a quiet rainfall period the contamination dropped every time to close to nothing. This means that there is to some extent natural attenuation of the water contamination that is effective after ten days or two weeks. This might also be explained by the top contaminated part being the one that is overflowed when the tank is full to be replaced by incoming water from the roof catchment. This natural removing of thermotolerant coliforms has been observed in the past, and the more tanks (and the more spread out the coliforms will be) the more effective this removing is (Ensslin, 2005).

Of all tanks, tank 7 is the one that gave the worst results, even though it is equipped with a 25L first flush diverter. Samples from this tank showed contamination at all occasions, with this time again contamination highs after heavy rainfall (sample two, four and six), with faecal contamination being absent on only two out of seven occasions. The most important contamination was observed on sample six, with over 200 total coliforms per 100mL and over 20 E.Coli per 100mL on both top and bottom parts of the tank. This time again, the top part always showed more total coliforms per 100mL than the bottom part. However in most cases that logic wasn't respected with E.Coli, this bacteria being more present at the bottom of the tank. Therefore it is possible that unlike environmental contamination, faecal contamination in a tank might settle down. In this tank there were also signs of natural attenuation, but not to the same extent as in the control tank as the water never reached drinking standards. These results of contamination heavier than in tank 6 which doesn't have a first flush diverter might have different explanations. The two tanks don't have exactly the same water catchment: tanks 5 and 6 get the rain collected by the side of the roof orientated towards the South, whereas tanks 7 and 8 get mostly rain collected by the other half of the roof that is orientated towards the North. Depending on the winds, it is possible that the North part collects more dirt and offers a nicer location for birds therefore getting more bird deposits. Another explanation might be the presence of a nest of contamination between the catchment and the tank 7, causing higher contamination of the harvested rainwater.

More surprising results were given by the samples taken in tank 8, equipped with a first flush diverter of 15L, smaller than that of tank 7. The results from these samples showed every time very good to excellent water quality, whatever the previous rain events were. Being connected to the same side of the roof as tank 8 and having a smaller first flush diverter, the results were expected to be worst. But the two tanks are connected in series to the gutter work, with tank 7 collecting the water first and tank 8 getting the leftovers. So it appears that tank 7 played the role of a giant first flush diverter for tank 8, collecting all the contaminated rainfall while tank 8 would only get clear water and which would explain such big differences in water quality.

The main results obtained from these samplings testing are that a heavy rainfall event emphasizes the water contamination of harvested rainwater as the dirt deposited on the roof is more easily removed, that the roof then remains relatively clean for around a week, and that there seems to be natural attenuation of both environmental and faecal contamination inside the tanks. Also, from the results obtained on the 120L first flush diverter it seems that during those heavy rainfalls a first flush volume of fifty to eighty litres needs to be diverted. However, such a large volume then means greater losses of harvested rainwater.

## 5. Rainwater tanks sizing

Nowadays, most rainwater harvesting tanks in use are oversized, which creates an increase not only of the purchase price but also of the maintenance costs. Depending on the local climate and the household's needs for water, having the right-sized tank will be as efficient as having a bigger one.

The size of rainwater tanks depend on many variables that must be taken into account in the configuration of the water harvesting system. Predominant factors are the size of the roof to which the tank will be connected, the volume and timing of rainfall in the specific area, the use and needs of water by the consumers, and the number of people living in the dwelling. The need of water in the household will depend on the internal and externals use practices: the capacity of the tank will change depending on whether the water will be used for toilet flushes and laundry, or for drinking as well, or if it will also cover the needs for gardening and car washing. Other variables to be taken into account when the use of water is calculated are the presence of water saving devices in the house like water-wise showerheads, half-flush toilets and front-loading washing machines.

The general footsteps include calculation of the collectable rain water per year, by using the annual rainwater estimates along with a security factor of 80% because of overload and spill; calculation of the annual needs in rainwater by the dwelling depending on its use practices; estimating the longest possible dry period in the area. Once all these numbers are known, a comparison is needed between the possible harvested volume of rainwater per year and the annual needs. The smaller of the two is taken to get the required water in the tank for the extent of the dry period, which gives the required tank capacity.

The following table, inspired by one designed by Rainwaterharvesting.co.uk, gives a practical example of tank sizing based on variables such as roof area, annual rainfall and the number of people living in the dwelling. Other variables can be modified depending on the area of the dwelling and the way water is used.

**Table 2: Tank sizing**

| | | | |
|---|---|---|---|
| **1** | **Main Building area** | | |
| | Building width (metres) | 10 | |
| | Building depth(metres) | 8 | |
| | **Rain Collection Area 1 (square metres)** | | 80 |
| **2** | **Extension/conservatory/porch/garage/shed etc** | | |
| | width (metres) | | |
| | Depth (metres) | | |
| | **Rain Collection Area 2 (square metres)** | | 0 |
| **3** | **Calculate the area of any remaining useful roofs as a figure in square metres and enter directly in the yellow box to the right** | | |
| **4** | **TOTAL of collectable roof areas (square metres)** | | **80** |
| **5** | **Rainfall per year in your area (mms)** | 1251 | |
| **6** | **Collectable rainwater per annum (in litres - discounted by 20% to account for water loss) (YIELD)** | | **80,064** |
| **7** | **Use of water in the building** | | |
| | *Washing machine and toilet flushing are the main usage for rain water in domestic systems. Add an allowance for daily garden use.* | | |
| | **Number of people in the house** | 5 | *people* |
| | **Number of clothes washing cycles per day (50 litres each)** | 1.25 | 63 |
| | **Number of toilet flushes per day (4.42 flushes per person, average 3 litres each)** | 22 | 66 |
| | **Outdoor use per day (min 5 litres per person per day)** *or adjust till F39 = F29 more or less* | | 35 |
| **8** | **Amount of water you require every day** | | 164 |
| | **Amount of water you require every year (DEMAND)** | | 59,787 |
| **9** | **How many days drought protection do you need?** Enter a number in the box to the right, typically 28 | | **28** |
| **10** | **Capacity of water storage in litres required for drought protection** | | **4,586** |
| | The lesser of YIELD (6) or DEMAND (8) per annum | | 59,787 |
| | **Therefore, volume of rainwater storage required (litres)** | | **4,586** |

By using this method with a 4 weeks drought protection and the national average of 160L used per person per day (including all the water uses and drinking), we obtain a required tank capacity of 5000L, which costs around 1500 NZ$.

For toilet flushing, different water calculators in the UK agree that a single person flushes the toilets on average 4.42 times a day, 33% of it being full flushes while the remaining 67% are half-flushes. While new WCs with 4/2.6 dual flush allow for an average flush volume of 3 liters or 13.6 liters per person per day, the majority of WCs in urban New Zealand are equipped with a 6/4 dual flush system which gives an average flush volume of 4.66 liters or 20.6 liters per person per day.

The average water consumption of washing machines does also need to be adapted to the practices in urban New Zealand. The usual UK water calculators agree on a water use of 50 liters per load with 0.25 loads per person per day. However, in England like in the rest of Europe more than 95% of the washing machines used are front-loaders which need less water as they use gravity with the spinning tub. On the other hand, and even though front-loaders are slowly appearing on the market, around 90% of New Zealand's washing machines are traditionally top loaders which use up to three times more water than front loaders. In the BRANZ study in Auckland (Matthias Heinrich, 2008), out of 51 households only three washing machines were used the front-loading system. Top-loaders will use between 120 and 150 liters per load against 40 to 90 liters for front-loaders. Using results of this study made in Auckland in the summer of 2008, as well as the appearance of front-loaders that can support the same weight loads, 120 liters per load can be kept, along with an average of 0.3 loads per person per day.

Outdoor water use varies a lot depending on the household, ranging from almost null to up to 50% of the total water use in the case of houses with big swimming pools / spas and important gardens. The New Zealand government gives a number of 20% of the total water consumption that is used for outdoor use, which does correspond to the 18% obtained by the BRANZ study made on 51 houses in urban Auckland during summer time (17% when it comes to water use per person). But this is an average, and looking closer at the BRANZ figures it comes out that more than half of the studied houses use less than 30 litres per day during the warmest months of the year, therefore the average outdoor water use for the following simulations will be taken down to 20 litres per person per day. This fits with the minimum of 5 liters per person per day recommended by general water calculators.

Therefore, combining water use for toilet flushing, washing machine and garden use gives an average of 77 liters per person per day.

Another approximate method for tank sizing is to globally visualize the minimum size of the tank needed compared to the size of the roof catchment and depending of the nature of the dwelling, on graphs such as the following:

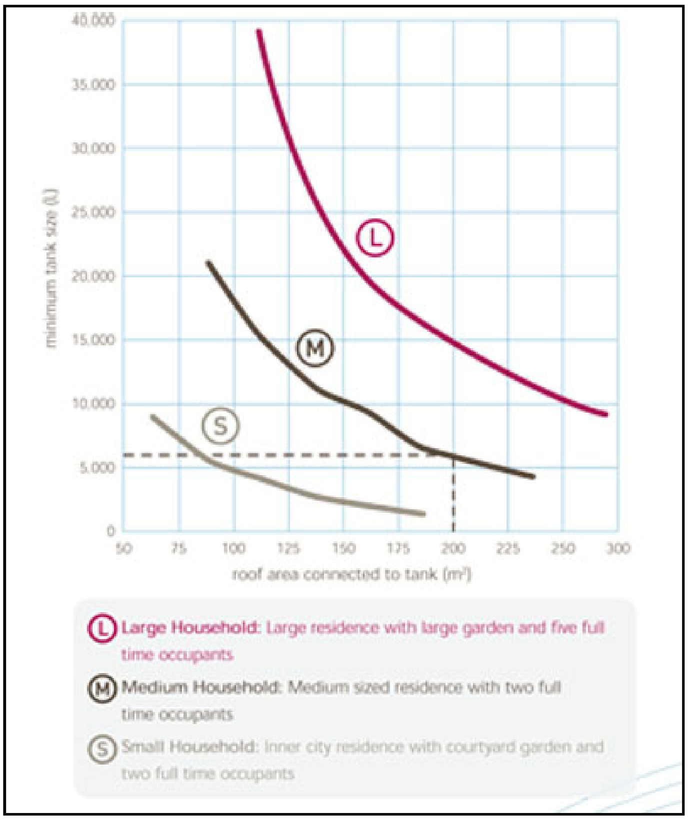


**Figure 12: Roof collection vs tank capacity for an area receiving 600mm of rain per year.**

Basically, the larger the roof catchment area is, the smaller the rainwater tank will need to be, as it will be much faster to refill during rain events. On the contrary, with a small catchment area less rain is collected during each rainfall, which calls for the need of  a larger tank so as to have a system that is more resilient especially in case of long lasting periods of drought.

However, the area available for rainwater tanks in urban environments is restricted by the proximity of houses and in some cases the lack of garden, so in most cases it is reasonable to consider the installation of a tank with a capacity in the 2000L-5000L range, which can come in the slimline fashion with a width of under a metre.

## 6. Cost-Benefits of rainwater tanks

We have seen that some NZ councils (Kapiti, Waitakare, North Shore, Rodney, Nelson and Upper Hutt) already support rainwater installation to new or existing houses. In these urban areas, the water thus collected is used mainly for toilet flushing, washing machines, car washing and swimming pools. The spreading of rainwater tanks helps to release the pressure exercised on the mains water system; an Australian study has shown that with a 1’000 liter tank between 18’000 and 55’000 liters could be saved annually, and with a 10’000 liter tank these savings reached as much as between 25’000 and 144’000 liters. Having them installed in a large number of urban households would therefore be an important supplement to centralized water supply and make it more resilient to natural climate variations as wells as unexpected climate changes.

The mains water in New Zealand is free in 62 of the 73 districts, and very cheap in the others compared to worldwide prices. In Auckland, it ranges from $1.28 per cubic meter (Manukau) to $2.33 (Whangaparaoa and Orewa) with an average $1.81 in Auckland City. In Wellington water is free with as a result a consumption of 400L per day per Wellingtonian, compared to the Aucklanders’ 300L and the national average of 160L per New-Zealander. This isn’t too far from the United States World Record in the domain of 600L per day per person, and there have already been talks on the possibility of charging water in the capital in 2008 which could reduce consumption by 20 to 40%. Unfortunately, free water seems to be a political untouchable in many parts of New Zealand which holds back any improvements in water use.

To compare prices, in Switzerland the national average water rate is $2.35 per cubic meter whereas it goes up to $5.78 on average in France with highs of up to $11.39. But whatever the country, the price of water is constantly rising worldwide (it has doubled in France over the last twenty years) and this dynamic will certainly be increased in the future, which emphasizes the interesting option of installing rainwater harvesting tanks. This price increase is illustrated in the following figure:

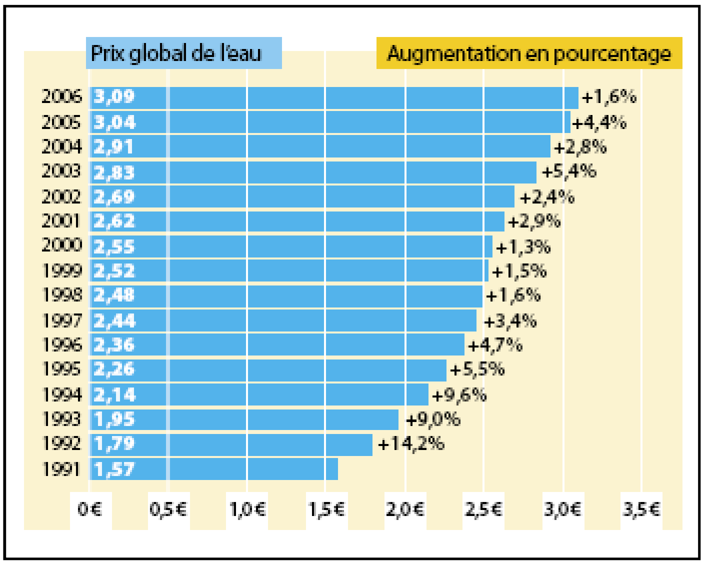


Figure 13: Growth of potable water prices in France over the last 20 years.

By comparing the price of water, the quantity of water possibly collectable over a year and the average price of a rainwater harvesting tank and system with the installation (but not including the maintenance), we can get an idea of the amount of money a tank can save every year, and the time it takes to become financially profitable in New-Zealand, Switzerland, France (on average, and in the region where the prices are the higher).

The costs of rainwater tanks vary through time and depend on their sizes, quality, material and fashion. To get an idea of the prices we are looking at, all the prices available from tank suppliers companies in New Zealand (list in annex 4) were compiled in order to get the mean price for different sizes of tank. These prices are for mid-2011, and are subject to change over the years. The results obtained are shown in the following table:

**Table 3: Tank prices depending on their size - 2011**

| Tank Size [L] | Tank type | Price Range [NZD] | Price average [NZD] |
|---|---|---|---|
| **1000** | Above ground, polyethylene | 495 - 710 | 569 |
| **3000 - 3500** | Above ground, polyethylene | 995 - 1192 | 1099 |
| **5000 - 5500** | Above ground, polyethylene | 1297 - 1752 | 1507 |
| **10000 - 12000** | Above ground, polyethylene | 1895 - 2850 | 2305 |
| **22500 - 25210** | Above ground, polyethylene | 2720 - 3270 | 2906 |
| **30000 - 30200** | Above ground, polyethylene | 3200 - 3680 | 3356 |
| **3044** | Underground, polyethylene | 2857 | 2857 |
| **27000** | Underground, ferro Cement | 4450 | 4450 |

The prices obtained show that actually in New-Zealand tanks with a size of 1000 litres can be very affordable, and common tanks of 5000 litres remain at a reasonable price regarding the efficiency they can provide as well as the fact they do not require too much room for installation. For tanks of respectively 10'000 litres and 20'000 litres the prices are 2300NZD and 290NZD which represents a big investment but can prove interesting in the case of rebates by local authorities and guarantee a huge supply of water may an emergency occur. These sizes may not however be fit to urban environment in many cases as they require a large amount of space. Another series of tanks that don't need much place at all and can fit almost anywhere are the slimline tanks for which the prices are given in the following table:

**Table 4: Slimline tank prices depending on their size - 2011**

| Tank Size [L] | Tank type | Price Range [NZD] | Price average [NZD] |
|---|---|---|---|
| **225** | Slimline, polyethylene | 199 - 378 | 289 |
| **1000 - 1250** | Slimline, polyethylene | 565 - 1199 | 825 |
| **3000 - 3500** | Slimline, polyethylene | 1900 - 3475 | 2688 |
| **5000** | Slimline, polyethylene | 2445 -4085 | 3265 |

For the same size than a normal tank these are twice or more than twice as expensive, which is the price for aestheticism or lack of room. It is important however to notice that very small tanks of 225 litres and tanks of around 1000 litres are also very affordable, and that the 3000 litres slimline tanks can be found at a reasonable price with some companies. Small tanks of around 200L should be recommended in every household as they are extremely easy to install, take almost no room and can prove to be extremely useful in the event of a disaster or a long term water shortage.

The following two tables show how much money can be saved in New Zealand, Switzerland and France with tanks of 1000 litres and 10'000 litres. This is based on Coombes and Kuczera (2003), Lucas et al. (2006), which give annual mains water savings ranging from 18'000 to 55'000 litres for a 1000 litres tank and from 25'000 to 144'000 litres for a 10'000 litres tank. The prices of water used where those mentioned previously of 1.81NZD per cubic metre in Auckland, the equivalent of 2.35NZD per cubic metre in Switzerland, and the equivalent of 5.87NZD per cubic metre in average in France with the maximum in the centre of the country with the equivalent of 11.39NZD per cubic metre. It is then possible to determine in average how much is saved per year with these tanks in those places. Furthermore, to get an idea of the time necessary for these savings to repay the starting investment the price of tank and installation have been estimated for these countries.

For a 1'000 litres tank, in New Zealand the price is of 570NZD on average with installation and maintenance costs of a maximum of 1'000NZD, so a safe 1'600NZD was taken. On the same basis, 2'000NZD were taken for the tank and installation in both Switzerland and France.

**Table 5: Benefits of a 1'000L tank**

| 1'000 litres tank | min saved (one year) [NZD] | max saved (one year) [NZD] | average saved (one year) [NZD] | time to repay [years] |
|---|---|---|---|---|
| Auckland | 32.6 | 99.6 | 66.1 | 24.2 |
| Switzerland | 42.3 | 129.3 | 85.8 | 23.3 |
| France mean | 105.7 | 322.9 | 214.3 | 9.3 |
| France max | 205.0 | 626.5 | 415.7 | 4.8 |

For a 10'000 litres tank, in New Zealand an overall of 3'200NZD was taken, which is again lower than the price for tank and installation in both Switzerland and France which is of 5'000NZD.

**Table 6: Benefits of a 10'000L tank**

| 10'000 litres tank | min saved (one year) [NZD] | max saved (one year) [NZD] | average saved (one year) [NZD] | time to repay [years] |
|---|---|---|---|---|
| Auckland | 45.3 | 260.6 | 152.9 | 20.9 |
| Switzerland | 58.8 | 338.4 | 198.6 | 25.2 |
| France mean | 146.8 | 845.3 | 496.0 | 10.1 |
| France max | 284.8 | 1'640.2 | 962.5 | 5.2 |

Tanks often come with 20 years warranties, and if well entertained their life expectancies could be double that number. Therefore, considering the little bit of maintenance necessary needed to keep the tank in good condition, the purchase in New Zealand will eventually become profitable before the end of its life time. The benefits are not only of economic nature though, and the user will enjoy the following advantages: have a water system more resilient than the mains water supply, have enough water for any use in periods of drought when water use is restricted, and have water supply in the case of a disaster like an earthquake when usual town water supply systems are damaged and unable to function. The case is the same in Switzerland, with tanks becoming profitable only on the long term, and with less risk of disasters. In France though, since the price of water is sensibly higher we get better economic results for users. Globally the rain water harvesting system will become profitable after a quarter of its life and after that will generate savings.

On a greater scale, the installation of rainwater collecting devices in important buildings for toilet flushing or in industrial zones for water use could significantly reduce the government's water bill. IN the region of Auckland, it is estimated that 25% of the potable water is used by industry which represents millions of dollars spent by local authorities for collecting, storing, treating and distributing this water (BRANZ 2008). Some commercial buildings in New Zealand have already taken the plunge of rainwater harvesting for the purpose of toilet flushing and non-potable uses, including the NZ Post building in Hamilton and the Conservation House in Wellington. Using rainwater for industry as well as other water consuming practices such as car washing in petrol stations could reduce much the national potable water demand.

Other benefits of introducing rainwater tanks on a big scale for industry and commercial buildings include:

- Decrease local authorities water bills
- Improve water supply security in times of water restriction
- Backup system in time of disaster, when mains systems are down (e.g. Christchurch earthquake)
- Reduction of need to build new infrastructure of bigger proportions to fight the increase in water use, such as Storage Lakes
- Reducing storm water runoff

This could benefit to both privates that decide to install rain collection systems as well as to the authorities who would face a lesser demand of potable water.

# 7. Tank Simulation

In order to get an idea of the efficiency of having a rainwater harvesting tank at home, some simple simulations show on a day-to-day basis the evolution of the rainwater contained in the tank depending on the rainfall and the household's water consumption. As the aim of these simulations are to get an overall idea of the behaviour of tanks in different situations and not to get precise continuous numbers for tank water quantity, a number of simplifying hypothesis have been made.

First of all, a daily time step has been selected in accordance to the available rainfall data. This excludes subtleties such as daily water consumption peaks and rainfalls of high intensity and short length of time, but gives a clear view of the tank's water reaction to exterior events on a larger time frame. Also, the daily household's water consumption has been set as constant, and the values used were the one calculated previously of 77 Litres per person per day, and another one of 50 Litres per person to represent a household with more reasonable consumption along with exclusively water saving devices. Furthermore, the rain catchment efficiency was set at 0.8, which includes roof and gutter spillage as well as loss through the first flush diverter equipped with drains holes of a diameter of 1.25mm (Gardner et Al. 2004). Different scenarios were tested with changing variables from one to another: The number of inhabitants, the size of the roof and the size of the rainwater tank.

The rainfall data used was measured in Newton by the Greater Wellington Regional Council and covers almost a year, starting on July the 14th 2009 and going to June the 17th 2010. With 1'051.5mm measured in 11 months, this period of time can be considered as over average in consideration to the amount of rainfall, and actually sits between the driest and most humid years of the last decade: 592.3mm in 2009 against 1203.2mm in 2010.

With a daily consumption of 77L per person, five case scenarios have been tested:

- A household of two, with a roof of 60 $m^2$ and a 5'000L tank
- A household of three, with a roof of 60$m^2$ and a 5'000L tank
- A household of four, with a roof of 100$m^2$ and a 5'000L tank
- A household of four, with a roof of 100$m^2$ and a 10'000L tank
- A household of four, with a roof of 100$m^2$ and a 20'000L tank

With those same four tested again in the case the rainwater was used only for garden use and washing machines, excluding toilet flushing. This scenario would put less strain on the tank, and would also allow for less infrastructure work in the house, as only the washing machine and a garden tap would have to be connected, generally both on the ground floor.

Another scenario taken into account is one with an amount of daily water use per person of 50 litres including washing machine, toilet flushing and garden use, and which might come true in the future given two criteria: the raising of the awareness of the population towards water use, and the development of new technologies in the domain of water saving devices.

The aim of the simulations is to obtain an idea of the part of consumed water that can be supplied by rainwater harvesting. Households of two, three and four people have been taken into account, as the national average is of 2.3 people per household. Graphs such as the following were obtained and show the level of filling of the tank on the wanted period along with the rainfall that occurred on the same period.

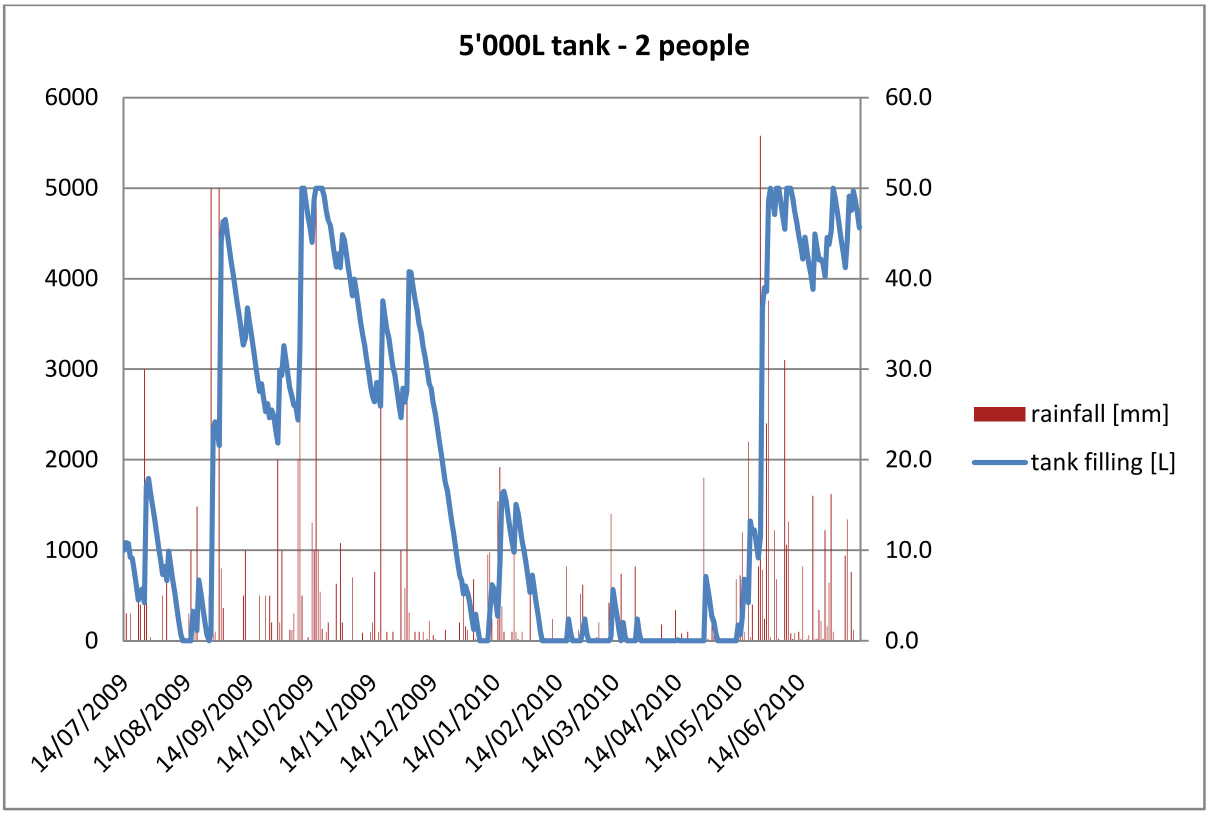


Figure 14: Tank filling with a consumption of 77L per person per day

This graph shows the level of filling of the 5’000 litres tank varying from 0 to 5’000 over the year, with some periods when it is almost full as well as some periods when there is no water left in the tank. These periods of the tank being empty can easily be correlated to low rainfall over time. We can see that in just over a month of drought the tank can get from close to full to empty, and on the other way a period of ten days with heavy rainfall is sufficient to refill it completely. This emphasizes the fact that the regularity of the supply is highly correlated to the hardly predictable factor which is rain. This particular scenario with two people using a 60 $m^2$ roof to fill in a 5’000 litres tank for a daily use of 77 litres per person for toilets, washing machine and garden use gives a result of close to 45’000 litres harvested which represents about 80% of the total water needed. When the tank is close to empty, usually a trickle top-up system uses a float at the bottom to trigger the input of mains water in order to maintain a desired minimum level of water in the tank.

For the same amount of requested water and other scenarios, the given results appear in the following table:

Table 7: water saved by using harvested rainwater with different scenarios

| Inhabitants | Size of roof [$m^2$] | Size of tank [L] | Water saved | Part of total used water [%] |
|---|---|---|---|---|
| 2 | 60 | 5000 | 44317 | 78.8 |
| 3 | 60 | 5000 | 52371 | 62.1 |
| 4 | 100 | 5000 | 75370 | 67.0 |
| 4 | 100 | 10000 | 80920 | 72.0 |
| 4 | 100 | 20000 | 82136 | 73.1 |

Having three people under the same conditions gives a net decrease in efficiency, but maybe not as important as expected with still over 60% of the needed water provided by roof harvesting. With four people and therefore a larger roof of 100$m^2$ but still the same tank size of 5000 litres, only two thirds of the needed water comes from rain, but that does represent over a year the large quantity of 75'000 litres. It is very interesting to note that increasing the tank size, even drastically to 20'000 litres doesn't have a lot of effect on the global efficiency of the process. Therefore, as a large emplacement is difficult to find in urban environments, keeping the tank small appears here to be a very good option.

The next case scenario was taken considering the absence of toilet use for the harvested rainwater, therefore getting the daily consumption of roof water to 56 litres per person. With the same infrastructure and less demand the aim is to see how much the efficiency would rise in such a case. The graph for two people using a 5000 litres tank has been displayed again for comparison.

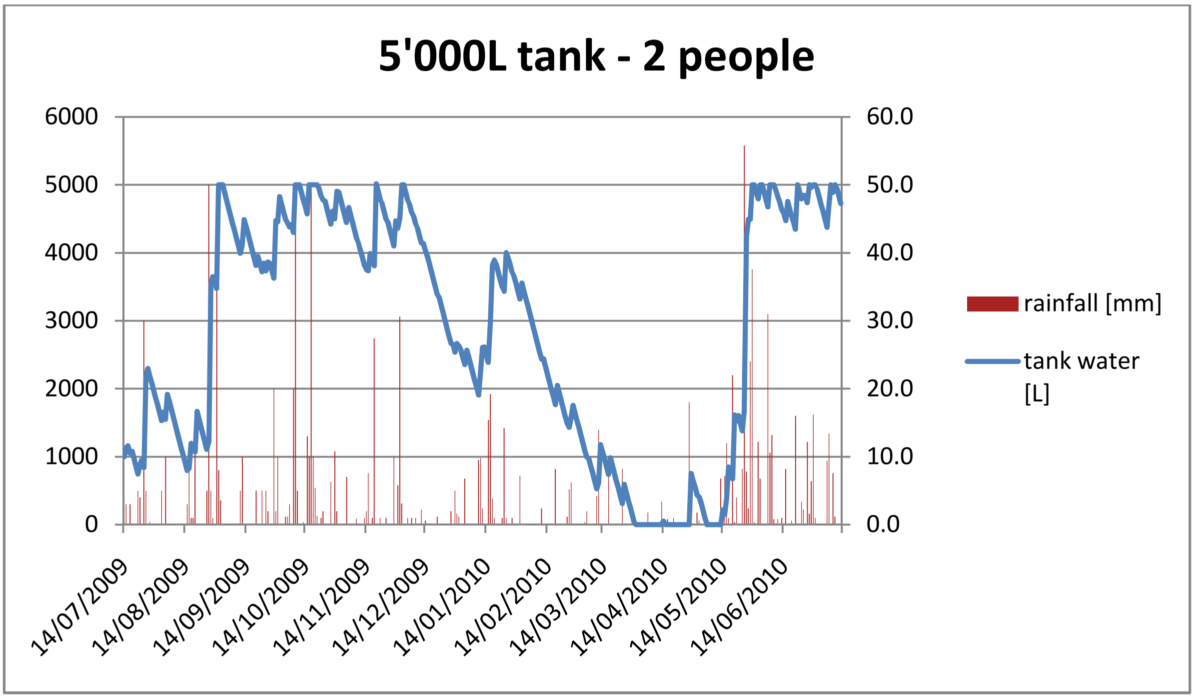


Figure 15: Tank filling with a consumption of 56L per person per day

We see on this graph that over the same period of time and the same infrastructure but a lower demand in rainwater, the tank is empty on only a concentrated period of 35 days over a whole year during which water will have to be taken from the mains water supply. Over a year however, more than 90% of the water needed for the washing machine and the garden use can be provided by roof water harvesting. Also, even though the consumption has been reduced by a quarter ,the time to get the tank filling from 4000 to 0 litres has doubled compared to the first scenario (66 days) making the tank twice as resilient in this case. The results obtained with the water used only for washing machine and garden use are given in the following table:

**Table 8: Water saved by using harvested rainwater with different scenarios, excluding toilet flushing**

| Inhabitants | Size of roof [m$^2$] | Size of tank [L] | Water saved | Part of total used water [%] |
|---|---|---|---|---|
| 2 | 60 | 5000 | 37337 | 91.3 |
| 3 | 60 | 5000 | 45970 | 75.0 |
| 4 | 100 | 5000 | 65864 | 80.6 |
| 4 | 100 | 10000 | 70864 | 86.7 |
| 4 | 100 | 20000 | 76928 | 94.1 |

All the results are better than in the previous case scenario, with the lowest efficiency being for a household of three under a 60m$^2$ roof with 75% of the water being provided by rainfall, and the highest efficiency being quasi perfect with 94% for a household of four with a very large tank of 20'000 litres. This time it appears that raising the storage volume of the tank does improve efficiency for the same household more significantly, and this can be explained by the slower emptying of the tank noted previously. With the emptying time doubling, having a tank two or four times larger can become interesting and therefore could be used in households that have the room for bigger tanks (under a deck, or in a large backyard).

The last case scenario was done with a very low water consumption of fifty litres per person per day, which could be made possible by combining new age water saving devices (flushes, washing machines and hoses) and especially awareness by the consumers in terms of economizing water, mainly by using it as little as needed for the garden. It is a very optimistic scenario that could be made possible by increasing scarcity of water or by increasing water prices. This time, the household of two with a 5000 litres tank reaches 96% efficiency in rainwater use:

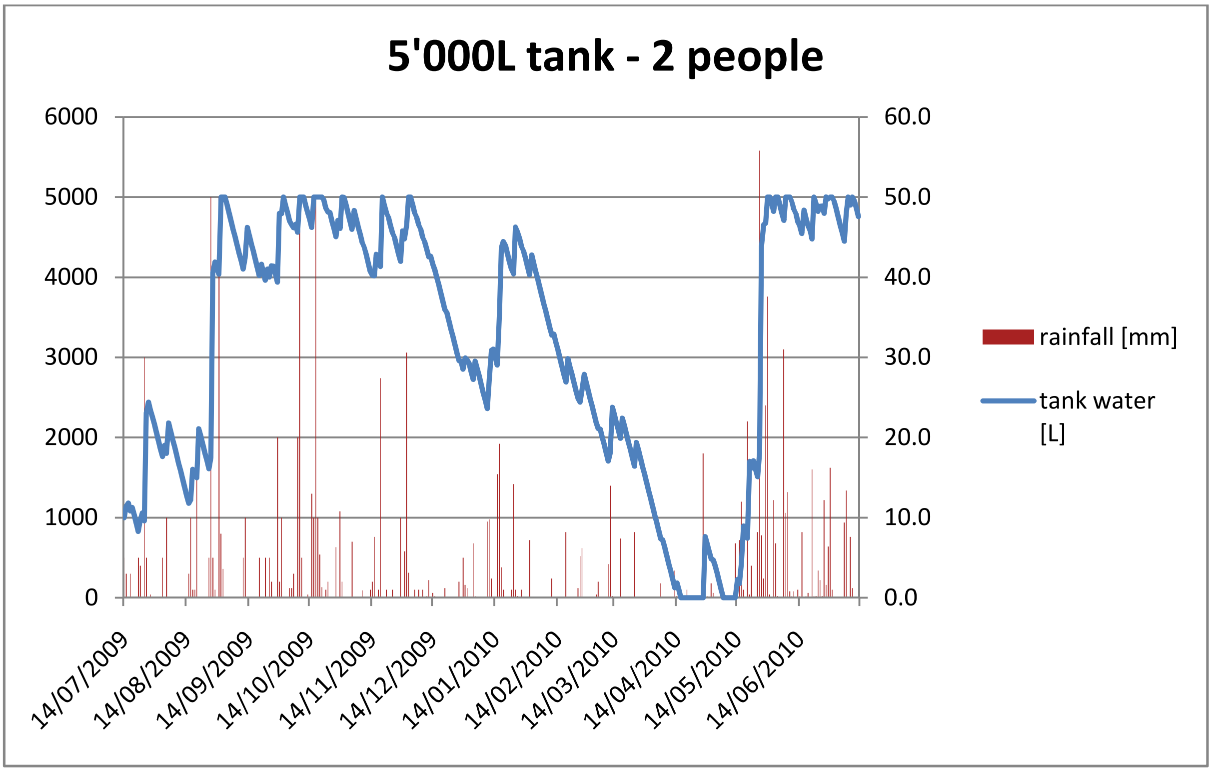


Figure 16: Tank filling with a consumption of 50L per person per day

This graph is very similar to the previous one as the water demand by the household is close (100 litres per day against 112 previously) but still the peaks due to heavy rainfall are enhanced and the emptying time has risen again a little bit more. This time the 5000 litres tank happens to be empty during only 19 days over the whole year in the same April/May period which represents the end of the driest part of the year. The results obtained with this low water consumption and other households are given in the following table:

Table 9: Water saved by using harvested rainwater with different scenarios, low water consumption

| Inhabitants | Size of roof [$m^2$] | Size of tank [L] | Water saved | Part of total used water [%] |
|---|---|---|---|---|
| 2 | 60 | 5000 | 34889 | 95.6 |
| 3 | 60 | 5000 | 43845 | 80.1 |
| 4 | 100 | 5000 | 61616 | 84.4 |
| 4 | 100 | 10000 | 66616 | 91.3 |
| 4 | 100 | 20000 | 73000 | 100 |

The results with this very optimistic case scenario all give higher than 80% efficiency for the rainwater harvesting process. For s household of three with a 60$m^2$ roof a 5000 litres tank seems sufficient over the year, and this time again the efficiency of having a larger tank increases considerably, getting to 100% with a 20’000 litres tank for a large household of four people. This scenario pictured on the following graph:

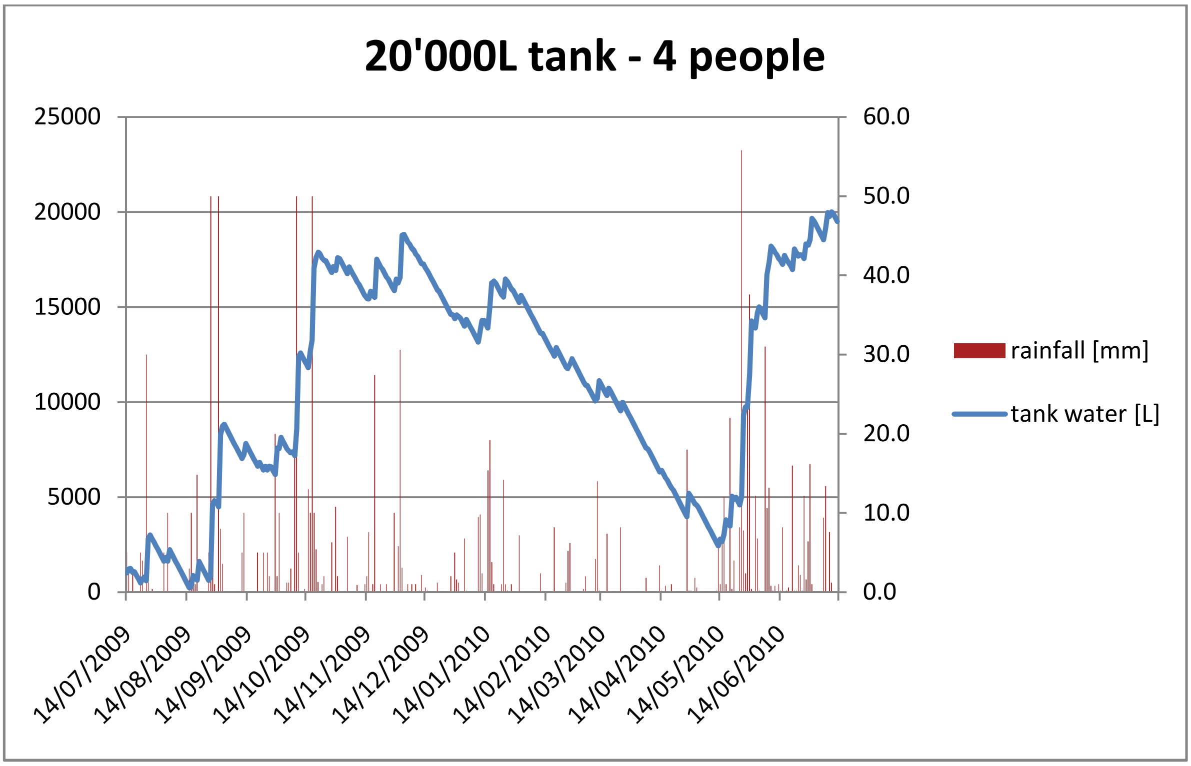


**Figure 17: Tank filling with a consumption of 50L per person per day**

This shows that depending only on harvested rainwater for some of the household's water use is possible over a year or more but hardly achievable nowadays and it would require a large tank and therefore a large garden or backyard. However, even with smaller tanks and higher water consumption rainwater harvesting is very efficient and can prove to be a very good alternative with a large amount of water saved in all the explored scenarios. Furthermore, having such tanks spread through the city can prove to be lifesaving in the case of high scale disasters such as earthquakes that easily destroy the mains water supply system and leave people queuing for water which is sparse when they could have a reserve behind the house.

The dependence to rainfall over a period of a year can be visualised on the following figure, which gives the average monthly rainfalls for New Zealand and its three bigger cities: Auckland, Christchurch and Wellington:

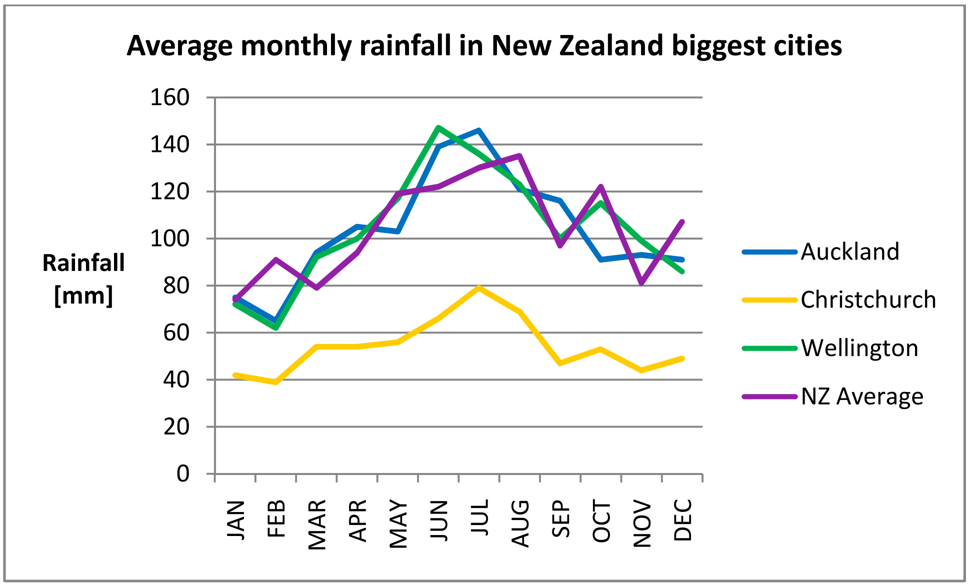


Figure 18: average New Zealand rainfall

In general, and especially on the north Island which is home to around 70% of New Zealand's population, the rain depends on the season: it rains a lot in winter, and months are drier in summer, as in all temperate climates. This means that as a general rule tanks should be full most of the time in winter but suffer from emptying during the summer.

# 8. Politics

The practice of rainwater harvesting is being increasingly encouraged all around the globe, but incredibly is illegal in some places. In some of the USA States (Utah, Washington, Colorado…), it is illegal to harvest rainwater without permit as it belongs to the State. Considering that Utah is the second driest State of the nation, forbidding its inhabitants the use of this important resource deprives them of backup supplies in case of long periods of drought.

In New Zealand however, the practice of rainwater harvesting is legal and in some cases it is also supported by local authorities. The size of the tanks allowed however does depend on the different councils, and all the information can generally be found straight on the council's website. On the large scale, promoting rainwater harvesting can prove to be interesting to the local authorities because not only does it reinforce and promote water conservation policies and practices in the public, but it relieves the pressure put on the mains water supply system and helps to make it more resilient in a time when water scarcity becomes more and more present. Therefore, rebates on the installation of rainwater tanks are already offered by several councils, and these depend on many factors such as the area where the household finds itself, the size of the installed tank and the presence of a stormwater detention system.

Different examples of such rebates offered include:

- Auckland City refunds developers 1'000 NZ$ when an approved rainwater tank has been installed for non-potable water supply in a newly built house. This lowers by half the payback period for the investment in the tank.
- The Kapiti council has approved Plan Change 75 for 2011/2012 which requires all new dwellings to either have a 10'000 litres rain water tank or a 4'000 litres rain water tank as well as a grey water diversion system. On top of that, a new interest-free loan scheme to encourage existing home owners to install water tanks was launched recently. Under this scheme, home owners will be required to pay back just the principle over a 10 year period through their rates.
- The greater Wellington Regional Council is actually debating on whether it should finance a new storage lake to ensure water supply for the capital city or subsidize water tanks for the households. The decision has yet to be taken, but going towards the rainwater harvesting option would be of great help to the development of such practice in urban environments and would certainly give more cases to study in the future in order to ameliorate the process.

Roof water collecting is difficult to put in application in countries such as Switzerland or France as the laws are an obstacle to an extended use of harvested rainwater, whereas leading countries such as New Zealand and Australia who bent the laws on water use and drinking water so as to allow for this practice now have more options regarding water management. In many cases it was originally made necessary as there was no other source of water available to dwellings, but it is now spreading and can become an important alternative source of water to be taken into account. It is also made attractive by the fact that such rainwater storing tanks act as stormwater detention devices which reduces a major problem many urban areas have to face. The future of urban rainwater harvesting depend greatly on the laws and the compliance of general and local authorities towards it, but as of today the trend is tending towards the acceptation and the development of this practice.

# 9. Earthquake and other disasters


**Figure 19: Water shortage after the Christchurch earthquake**

Rainwater tanks can also play a major role in the case of unforeseen disasters such as fires, earthquakes, storms and hurricanes etc… The proof has been made in Christchurch recently, when New Zealand's second biggest cities was hit by a magnitude 6.3 aftershock only 5km deep on February the 22nd 2011. This seism cut off most of the drinking water and wastewater systems producing a very important lack of potable water in the city on the days following the disaster, to the point that Christchurch's mayor Bob Parker had to recommend his people to fill buckets with rain as often as it was on offer. The shake also started fires throughout the city, emphasizing the need for a secure source of water for the firefighters to have easy access to. Rainwater tanks would have been extremely useful on this occasion, had they been present like it is the case in Wellington with a planned forty-five emergency tanks spread over the city in places like schools, sport centres or meeting points.

Some of these 25'000 litres tanks have already been installed, and in order to test the quality of the water they contain, two sampling campaigns have been conducted. On the first one, made on April the 7th 2011, six samples were taken on two of these tanks in schools around Wellington (Pukerua Bay School and Discovery School) and then tested (Results in annex 5). The total coliform results show that at the time of sampling the Discovery School rainwater tank showed slight to heavy environmental contamination, and the Pukerua Bay School tank showed very heavy environmental contamination. The *E.coli* results show that this last tank also showed slight faecal contamination, whereas the other tank wasn't contaminated. On the second campaign, made on May the 26th 2011, those two tanks were tested again along with three others (Tairangiy School, Adventure School and Postgate School, again all in the Wellington Region). The results for Pukerua Bay School and Discovery School were relatively similar to those obtained on the first campaign: heavy environmental and slight faecal contaminations for the first, slight environmental and no faecal contaminations for the second one. The results for the Tairangiy School tank showed heavy environmental contamination and no trace of faecal contamination, those for Adventure School showed again heavy environmental contamination along with slight faecal contamination, whereas the samples from the last tank in Postgate School showed very heavy environmental and heavy faecal contamination. These last results were the worst obtained on both campaigns: more than 1'500 total coliforms per 100ml on average and around 15 E.Coli per 100ml.


Figure 20: Civil defence sticker for water boiling on an emergency tank

These are relatively good results in relation to the purpose of these tanks: water with environmental contamination is way better than no water at all, and that water will be boiled before consumption as is stated on signs placed in clear view on the tank, and therefore the water will be rid of its bacteria. In cases where it is impossible to do so, water could be treated with the SODIS method (Sodis 2005) to ameliorate its quality. Also, it is important to remark that the quality water from rainwater tanks can vary a lot through time and depends on many exterior and interior factors. Furthermore, the field trip revealed in some cases lack of general water quality enhancers such as first flush diverters as well as examples of bad maintenance (improperly fixed pipes, improperly fitted diverter), and it is now planned that caretakers of the place where the security tanks are should follow proper training on rainwater harvesting systems installation and maintenance. It is then unnecessary to test regularly the quality of this water as it will change in time and as it will very likely be boiled; good maintenance should be the standard.

Yet another option that would avoid a lot of troubles if it was done by a majority of the households would be to install small rainwater harvesting tanks that can be used for garden use in normal conditions but can change into a reliable supply of water would the town's mains water supply fail. Such tanks can be found in the 200 to 250 litres range and can cost as little as 200NZD, and are easy to install in half an hour. This initiative has to be advertised and brought to as many people's attention as possible, showing that a small investment can prove to be handy on a normal basis and primordial on some occasions.

In the absence of such back-up tanks, I've explored the possibility of designing self-harvesting stackable tanks that would be easy to transport and put to use even in the absence of a functioning roof to harvest from or in situations where access to a roof catchment is not immediately possible or feasible. The design concept of these tanks lend themselves to easy, simple and quick assembly –

essential for emergency situations such as earthquakes when mains water infrastructure is compromised.

With tanks of capacity of around 5’000L, we usually get a catchment area close to 3.8m$^2$ (diameter will be around 2.2m) and if we consider that 10% of rainfall is lost mostly due to spill, we obtain quantities of water that are not very consequent with 15mm of rain required to fill 1% of the tank, even though it is still better than nothing.

It is then a very interesting option to associate a tarpaulin held by poles above the self-harvesting tank with a hole in the centre placed so as to lead all the rainwater towards the tank. There are two possibilities for the assembly of this system:

- The first one with four poles fixed directly on opposite sides if the tank and the tarpaulin attached to those poles over it, in order to have a system that is completely independent of the nature of the ground and of surrounding elements. There are multiple possibilities for the positioning of the poles, a seemingly realistic one being the use of 4 metre long poles fixed to the tank at an angle of 40° with the horizontal. This configuration gives excellent harvesting results with its catchment area close to 35 m$^2$, being able to collect 3’200 litres in Wellington on an average month (the 10% of spill-off being applied). A chain can be fixed to the tarpaulin’s outlet so as to get the water on the lid with minimum spill.

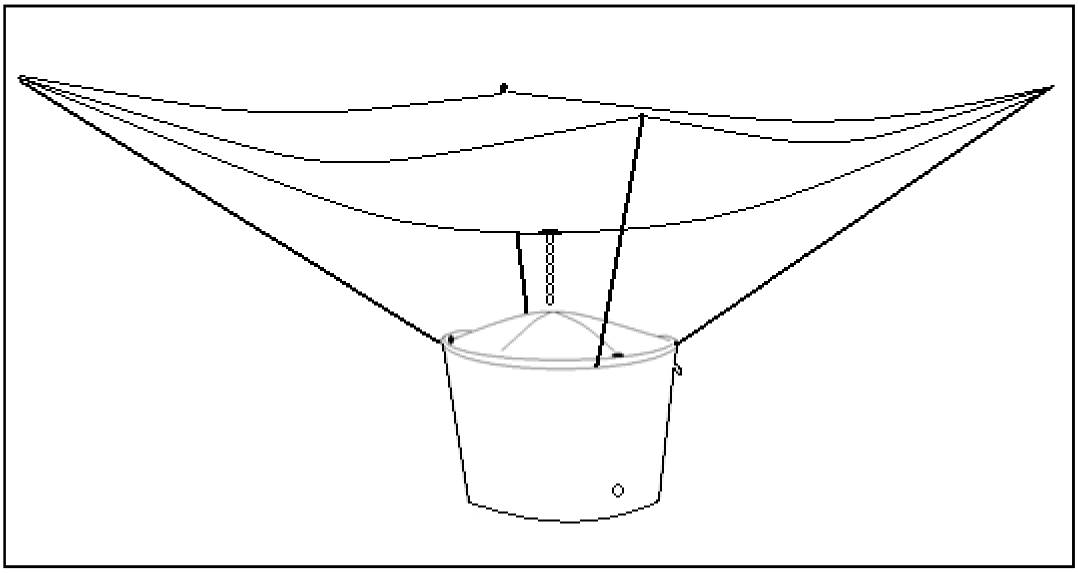

Figure 21: Self-harvesting tank for emergency situations

- The other option is system tarpaulin/poles independent from the tank, and set up around it so that the collected rainwater also runs down to the tank. This option allows for greater catchment area, and the fixation of the poles to the ground will depend on its nature, with solutions possible for any type of location. There again 4 metre long poles can be used along with different tarpaulin sizes, a realistic and advantageous one being of 8 metres sides. This would give a catchment area of 64 $m^2$, which is enough to fill a 6'000 litres tank with rainwater in an average Wellington month.

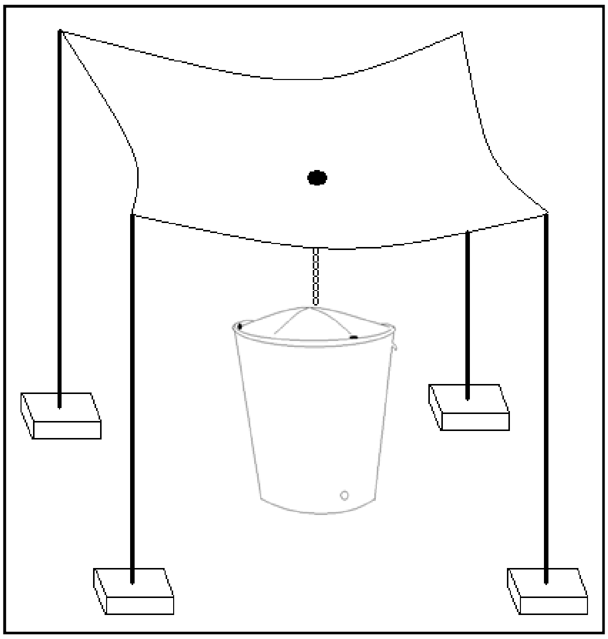

**Figure 22: Self-harvesting tank for emergency situations**

Following is a table that gives some possible harvested quantities of rainwater by those two systems in different parts of the world over short periods of time:

**Table 7: Quantity of water self-harvested**

| Region | Rainfall [mm] | Tank with fixed tarpaulin [L] | Tank with independent tarpaulin [L] |
|---|---|---|---|
| **Christchurch, week after the earthquake** | 13 | 398 | 749 |
| **Christchurch monthly average** | 56 | 1714 | 3226 |
| **Wellington monthly average** | 105 | 3213 | 6048 |
| **Wellington, 8-19 October 2009** | 164 | 5018 | 9446 |
| **Wellington, 24-29 may 2010** | 136 | 4162 | 7834 |
| | | | |
| **Brisbane, December 2010 (floods)** | 500 | 15300 | 28800 |
| **Solomon Islands (Honiara), monthly average** | 181 | 5539 | 10426 |
| **Solomon Islands (Honiara), march average** | 362 | 11077 | 20851 |
| **Fiji, monthly average** | 172 | 5263 | 9907 |
| **Fiji, 418mm in 19 days (march)** | 418 | 12791 | 24077 |
| **Samoa (Apia), monthly average** | 241 | 7375 | 13882 |
| **Samoa (Apia), January average** | 437 | 13372 | 25171 |
| | | | |
| **Haiti, rainy season: around 150mm/month** | 150 | 4590 | 8640 |
| **Ivory Coast monthly average** | 179 | 5477 | 10310 |
| **Indonesia, during monsoon** | 200 - 340 | 6120 - 10404 | 11520 - 19584 |
| **Bangladesh, during the summer** | 250 - 340 | 7650 - 10404 | 14400 - 19584 |
| **Lausanne, monthly average** | 65 | 1989 | 3744 |
| **China, wettest period (13 days in July)** | 243 | 7436 | 13997 |
| **South Africa (Durban) monthly average** | 84 | 2570 | 4838 |

# Conclusion

The practice of rainwater harvesting is not yet developed in New Zealand's urban areas, but this could very well change in the future as different aspects show that it is feasible.

First of all, this water supply system has been present in many of New Zealand's rural areas for a long time now with success, so the people's reception to such infrastructure is high and the rainwater tanks market is large with a lot of healthy concurrence that give many different choices and some affordable prices. One of the main regards is the water quality this practice delivers, as many sampling and testing has been done in a large number of existing tanks with results showing contamination in 70% of them in private dwellings of rural New Zealand. The inhabitants drink that water and have done so for year, but it is accepted the disease outbreaks it causes and particularly gastroenteritis are currently widely underreported. Many bacteria are collected with the rainwater as they deposit on the roof or in the gutters because of wind or animals.

The water quality tests effectuated on the Roof Water Research Centre tanks showed that both environmental and faecal contamination occur in the tanks especially after heavy rainfall events as they are more likely to clean deeply the catchment roofs. Observed contamination reached up to 250 total coliforms per 100mL and 30 E.Coli per 100mL in a tank. Different treatment can ameliorate the harvested water's quality, from filtration to UV treatment, but one that should be included to every rainwater harvesting system is the first flush diverter. The required flushed volume depend on the intensity of the rainfall events, but it was found through testing of a 120 litres diverter that a volume ranging from fifty to eighty litres would be enough to supply the storage tank with good quality water.

Tank prices vary mostly on their sizes, and so does water supply efficiency but on a smaller scale. Therefore a 5'000 litres tank that cost 1'500NZD which is affordable and give efficiency between 60% and 95% over a year depending on the household can be preferred to larger tanks of 10'000 0r 20'000 litres which cost more, don't improve the efficiency a lot and take much more space. The ideal tank definitely depends on the household but will always have an interesting rate of efficiency.

An actual setback to the spreading of rainwater tanks in urban New Zealand is the very low price of water, which is free in Wellington and doesn't contribute to making people aware of reducing their consumption. These low prices also extend a lot the payback period for bought rainwater tanks making them less interesting. However, like all around the World water prices are slowly rising and local authorities are starting to push towards the implementation of rainwater harvesting systems on a larger scale making it compulsory already in some places, and this combination of changes should push in the future towards the development of rainwater tanks in New Zealand's cities.

Another advantage of rainwater tanks towards which people are getting more sensible nowadays in view of the recent earthquakes in Christchurch and which could help accelerate the multiplication of tanks regardless of price and politics is the great help they can bring in the case of natural disasters. Even having a small 200 litres tank at home can prove to be vital in the event of long term water shortages due to mains water systems failure as it gives a regular supply of water that can be used to any ends after it has been boiled.

So even though it might take ten or fifteen years, the water management in New Zealand has been linked to rainwater harvesting for some time already and the fact that main criteria such as water quality, price and efficiency go in the same direction, rainwater harvesting in New Zealand's urban environments will soon be a reality on a large scale. The time it is going to take however does depend a lot on population awareness and on the politic decisions taken by different councils in the future.

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Source for average monthly rainfall: National Institute of Weather and Atmospheric Research (niwa.co.nz)

# Annexes

## Annexe 1

Waitarere campaign – 11/03/2011

| Sample ID | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
|---|---|---|
| 2 | 307.6 | 0.0 |
| 5 | 41.7 | 1.0 |
| 6 | 23.3 | 11.0 |
| 9 | 686.7 | 9.6 |
| 11 | > 2419.6 | 28.8 |

## Annexe 2

Brooklyn tank – 08/04/2011

| Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
|---|---|---|
| Bottom | 866.4 | 0.0 |
| Middle | 1203.3 | 1.0 |
| Top | 1046.2 | 0.0 |

Karori tank – 21/03/2011

| Sample ID | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
|---|---|---|
| 717 | 165.8 | 8.6 |

Nelson tanks– 22-29/05/2011

| Sample ID | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
|---|---|---|
| M.S. | 0.0 | 0.0 |
| J.O. | 62.0 | 0.0 |

# Annexe 3

| Sample 1 – 31/03/2011 | | | Sample 2 – 06/04/2011 | | |
|---|---|---|---|---|---|
| Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) | Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
| B1 A | 3.0 | 0.0 | B1 A | 0.0 | 0.0 |
| B1 B | 0.0 | 0.0 | B1 B | 0.0 | 0.0 |
| B2 A | 0.0 | 0.0 | B2 A | 4.1 | 0.0 |
| B2 B | 0.0 | 0.0 | B2 B | 2.0 | 0.0 |
| B3 A | 0.0 | 0.0 | B3 A | 1.0 | 0.0 |
| B3 B | 0.0 | 0.0 | B3 B | 290.9 | 19.5 |
| B4 A | 0.0 | 0.0 | B4 A | 65.0 | 2.0 |
| B4 B | 0.0 | 0.0 | B4 B | 6.3 | 0.0 |
| B5 A | - | - | B5 A | 12.1 | 1.0 |
| B5 B | - | - | B5 B | 7.4 | 3.0 |
| | | | | | |
| T5 A | 0.0 | 0.0 | T5 A | 0.0 | 0.0 |
| T5 D | 0.0 | 0.0 | T5 D | 2.0 | 0.0 |
| T6 A | 1.0 | 0.0 | T6 A | 25.9 | 3.1 |
| T6 D | 3.0 | 0.0 | T6 D | 35.0 | 5.2 |
| T7 A | 7.5 | 0.0 | T7 A | 125.9 | 7.5 |
| T7 B | 7.4 | 0.0 | T7 B | 101.4 | 9.8 |
| T8 A | 0.0 | 0.0 | T8 A | 0.0 | 0.0 |
| T8 B | 0.0 | 0.0 | T8 B | 0.0 | 0.0 |

| Sample 3 – 12/04/2011 | | |
| --- | --- | --- |
| Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
| **B1 A** | 1.0 | 0.0 |
| **B1 B** | 0.0 | 0.0 |
| **B2 A** | 3.0 | 0.0 |
| **B2 B** | 3.0 | 0.0 |
| **B3 A** | - | - |
| **B3 B** | - | - |
| **B4 A** | - | - |
| **B4 B** | - | - |
| **B5 A** | - | - |
| **B5 B** | - | - |
| | | |
| **T5 A** | 1.0 | 0.0 |
| **T5 D** | 1.0 | 0.0 |
| **T6 A** | 2.0 | 0.0 |
| **T6 D** | 1.0 | 0.0 |
| **T7 A** | 23.1 | 3.1 |
| **T7 B** | 20.1 | 0.0 |
| **T8 A** | 0.0 | 0.0 |
| **T8 B** | 0.0 | 0.0 |

| Sample 4 – 25/04/2011 | | |
| --- | --- | --- |
| **Sample** | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
| B1 A | 0.0 | 0.0 |
| B1 B | 5.2 | 1.0 |
| B2 A | 0.0 | 0.0 |
| B2 B | 0.0 | 0.0 |
| B3 A | 0.0 | 0.0 |
| B3 B | 107.6 | 0.0 |
| B4 A | 6.3 | 2.0 |
| B4 B | 13.4 | 0.0 |
| B5 A | 0.0 | 0.0 |
| B5 B | 0.0 | 0.0 |
| | | |
| T5 A | 1.0 | 0.0 |
| T5 D | 0.0 | 0.0 |
| T6 A | 17.3 | 0.0 |
| T6 D | 12.2 | 0.0 |
| T7 A | 137.6 | 1.0 |
| T7 B | 116.9 | 2.0 |
| T8 A | 0.0 | 0.0 |
| T8 B | 1.0 | 0.0 |

Sample 5 – 11/05/2011

| Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
|---|---|---|
| **B1 A** | 0.0 | 0.0 |
| **B1 B** | 0.0 | 0.0 |
| **B2 A** | 0.0 | 0.0 |
| **B2 B** | 0.0 | 0.0 |
| **B3 A** | 0.0 | 0.0 |
| **B3 B** | 0.0 | 0.0 |
| **B4 A** | 1.0 | 0.0 |
| **B4 B** | 0.0 | 0.0 |
| **B5 A** | - | - |
| **B5 B** | - | - |
| | | |
| **T5 A** | 0.0 | 0.0 |
| **T5 D** | 0.0 | 0.0 |
| **T6 A** | 1.0 | 0.0 |
| **T6 D** | 1.0 | 0.0 |
| **T7 A** | 66.3 | 0.0 |
| **T7 B** | 70.6 | 0.0 |
| **T8 A** | 0.0 | 0.0 |
| **T8 B** | 0.0 | 0.0 |

Sample 6 – 20/05/2011

| Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
|---|---|---|
| B1 A | 0.0 | 0.0 |
| B1 B | 0.0 | 0.0 |
| B2 A | 1.0 | 0.0 |
| B2 B | 19.7 | 21.1 |
| B3 A | 547.5 | 0.0 |
| B3 B | 0.0 | 0.0 |
| B4 A | 0.0 | 0.0 |
| B4 B | 0.0 | 0.0 |
| B5 A | 0.0 | 0.0 |
| B5 B | 0.0 | 0.0 |
| | | |
| T5 A | 0.0 | 0.0 |
| T5 D | 0.0 | 0.0 |
| T6 A | 57.6 | 30.9 |
| T6 D | 36.4 | 20.3 |
| T7 A | 248.1 | 21.6 |
| T7 B | 224.7 | 24.9 |
| T8 A | 1.0 | 0.0 |
| T8 B | 1.0 | 1.0 |

Sample 7 – 30/05/2011

| Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
|---|---|---|
| B1 A | 0.0 | 0.0 |
| B1 B | 0.0 | 0.0 |
| B2 A | 0.0 | 0.0 |
| B2 B | 0.0 | 0.0 |
| B3 A | 0.0 | 0.0 |
| B3 B | 0.0 | 0.0 |
| B4 A | 0.0 | 0.0 |
| B4 B | 0.0 | 0.0 |
| B5 A | - | - |
| B5 B | - | - |
| | | |
| T5 A | 0.0 | 0.0 |
| T5 D | 0.0 | 0.0 |
| T6 A | 3.1 | 0.0 |
| T6 D | 1.0 | 0.0 |
| T7 A | 72.7 | 4.1 |
| T7 B | 66.3 | 7.4 |
| T8 A | 0.0 | 0.0 |
| T8 B | 0.0 | 0.0 |

## Annexe 4

| Tanks Supplier Company | Company website |
|---|---|
| Aqua Tanks | www.aquatanks.co.nz |
| Bailey Tanks | www.tanks.co.nz |
| Bowers & Son Ltd | www.bowersconcrete.co.nz |
| Devan Group | www.devan.co.nz |
| Duracrete | www.duracrete.co.nz |
| Fibreglass Tanks and Manufacturing Ltd | www.fibreglasstanks.co.nz |
| Green Tank | www.greentank.co.nz |
| Gutter Tank | www.gutterwitch.co.nz |
| Hydroflow | www.hydroflow.co.nz |
| Kliptank | www.kliptank.com |
| Larsen & Sons Eletank | www.eletank.co.nz |
| McKee Plastics | www.mckeeplastics.co.nz |
| New Water | www.newwater.co.nz |
| Plastic Systems Ltd (Kiwi Tanks) | www.kiwitanks.co.nz |
| Promax Engineered Plastics | www.promaxplastics.co.nz |
| Rhino Tanks & Liners | www.rhinotanks.co.nz |
| RXP Tanks | www.rxplastics.co.nz |
| Tanks Alot | www.tanksalot.co.nz |
| Tasman Tanks | www.tasmantanks.com.au |
| Timbertanks | www.timbertanks.co.nz |
| Wright Tanks Ltd | www.wrighttanks.co.nz |

# Annexe 5

Security tanks campaign 1– 07/04/2011

| Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
|---|---|---|
| **Pukerua 1** | 613.1 | 0.0 |
| **Pukerua 2** | 547.5 | 1.0 |
| **Discovery 1** | 15.6 | 0.0 |
| **Discovery 2** | 6.3 | 0.0 |
| **Discovery 3** | 6.3 | 0.0 |
| **Discovery 4** | 33.2 | 0.0 |

Security tanks campaign 2 – 26/05/2011

| Sample | Total coliforms (per 100ml) | Escherichia coli (per 100ml) |
|---|---|---|
| **Pukerua 1** | 2419.6 | 4.1 |
| **Pukerua 2** | 2419.6 | 2.0 |
| **Tairangiy 1** | 63.1 | 0.0 |
| **Tairangiy 2** | 74.9 | 0.0 |
| **Adventure 1** | 88.4 | 1.0 |
| **Adventure 2** | 93.2 | 1.0 |
| **Postgate 1** | 2419.6 | 18.3 |
| **Postgate 2** | 727.0 | 9.6 |
| **Discovery 1** | 5.2 | 0.0 |
| **Discovery 2** | 8.6 | 0.0 |