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Self Sufficiency of Water in Mainstream Housing - An Australian Experience

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Abstract: It is ideal to have a goal of reaching self sufficiency in water for the promotion of sustainable housing principles. Although there are many small projects of rainwater harvesting, it is yet to be used in mainstream large planned housing developments, which is essential for its successful implementation. There are many associated issues including social acceptance, reliability, cost effectiveness and the feasibility of combining it with the town water supply in an efficient manner. Many of these issues were addressed by implementing a rainwater harvesting system in three *Green Smart* display homes constructed in a large housing scheme planned for 20,000 houses in Australia. This paper describes the planning, implementation, special features and cost aspects relating to the rainwater harvesting system used in the *Green Smart* homes and provides a useful example for future larger scale initiatives.

Key words: Rain water harvesting, sustainable development.

Introduction

Australia is the driest inhabited continent in the world. However, the water appetite per person is increasing with the increased usage of new appliances such as dish washers, washing machines, etc. This increasing water consumption places Australia with the considerable challenge of providing adequate and continuous water supply for its growing population in conjunction with its expanding agricultural and industrial sectors. With the changing global climatic conditions, there have been continuing drought and changed weather conditions increasingly over the last five to ten years which have seen the introduction of water restrictions in most major Australian cities. The result of this has been an increased public awareness that provision of adequate quantity of water of acceptable quality is an important issue that will have an impact on the quality of life. In this context, harvesting of rain water for mainstream housing is very important.

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There is another interesting aspect that makes Australian housing sector a good candidate for rainwater harvesting. Over 11% of Australians rely on captured roof water as their primary drinking source (ABS, 1997). However, this widespread usage of rainwater has not caused any significant health problems so far. Quality of water from tanks can vary depending on their catchment system, on-going maintenance and location of the roof and tank relative to pollution sources such as busy or dusty roads and industrial areas. Water quality is not a major problem if the water is for non-potable uses like toilet flushing or garden watering (Cunliffe, 2004). With both potable and non-potable uses envisaged, the responsibility of maintaining adequate quality should shift back to the house occupants who have a vested interest in their own health and this can be used to motivate regular maintenance.

With increasing urban expansion around major Australian cities, there is an urgent need to make the water supply sustainable. An important question is "can the mainstream housing approach self sufficiency through the use of rainwater tanks?" An attempt was made to address this question by implementing an innovative rainwater harvesting solution in three display homes, called *Green Smart* houses, that were built in a large development planned for 20,000 houses about 30 km south-west of Brisbane (Queensland's capital city). This paper describes the various water issues related to housing and explores the different options, their costs, benefits and the experience drawn from the construction of the three *Green Smart* homes. The homes also incorporated many water efficiency elements in a substantial move towards water sustainability.

The Objectives and Methodology

The main objective of this research is to develop a dependable rainwater harvesting system that can be integrated with reticulated supply thus realizing the goal of achieving greater water self sufficiency for individual houses and thereby enhance the sustainability of future large scale residential developments. The following methodology was adopted:

1. The average water usage patterns of Australian houses were evaluated.
2. The storage tank capacities and the probable savings of water were evaluated.
3. A system that can automate and ensure a continuous water supply while maximizing the usage of rainwater was devised.
4. A cost benefit analysis was used to highlight the various decisions that may be needed to popularize such systems.

The Water Needs in Houses

The water needs in houses can be divided into two main categories:

- Internal – kitchen uses (drinking, cooking, dishwashing), toilets (flushing), bathroom (showers, baths, vanities), laundry (washing machine, tub or sink).
- External – garden, car, house and pet washing, pools, spas and water features.

Past studies have indicated different allocations for water use in houses which may be due to climate, social variability or the method of interpretation. Table 1 highlights some values currently used by different city councils and two results that were observed in two houses monitored over a long period.

The first three entities in the table show indicative trends of "the average house" with external use being the main water consumption area. Drinking water quality is not required for garden and toilet which accounted for about 45% or more of the total usage. Laundry and bathroom also could qualify as areas not needing potable water if the quality of water supply is good. The last two rows of the table are operational houses that have had their water consumption monitored over several years. These two houses located in different climate zones have different styles and areas of garden, construction and fit-out inclusions. This may account for their water use variations. Both these houses have a reduced total water usage when compared to average conventional housing to which the other entities relate. The measured internal and external water usage of the healthy house over four years was 515 litres and 80 litres per day, respectively, totalling 595 litres/day (Gardner et al., 2003; Healthy Home, 2005). The average water usage of the Research House in Rockhampton was 1150 litres/day (DPW, 2005). The water usage of a conventional house is generally considered as about 1000 litres/day. This gives a water usage of about 150-200 litres/day for flushing of toilets with 15-20% of usage. In a study carried out in United Kingdom (Fewkes, 1999a), it was found that water closet flushing demand varies between 154 and 217 litres/day which is equivalent to 17-24 flushes. Thus, the above percentages are indicative of the actual usage.

Advantages of Rainwater Usage

The capture and use of rainwater for domestic use can have many advantages such as the reduction in reticulated supply pipe sizes, pumping costs, maintenance costs and upstream storage costs. Large number of storage tanks

Table 1: Partitioning of water use in residential housing

Source	*Kitchen %*	*Bathroom %*	*Laundry %*	*Toilet %*	*External %*
Ipswich City Council	10	15	15	15	30
Gold Coast City Council	14	21	20	15	30
Brisbane City Council	11	28	7	10	44
Healthy Home - Gold Coast*	13	37	15	21	14
Research House – Rockhampton**	14	19	6	10	51

* Gardner et al., 2003; Healthy Home, 2005. ** DPW, 2005.

in a residential development can reduce the impacts on the storm water system. In a feasibility study by Gold Coast Water (GCW, 2004), a south-east Queensland local authority, completed in May 2004 for its proposed development in Pimpama Coomera Water Futures Project study, has revealed many important possibilities. This project covered an area of 5292 ha with a predicted future population of some 150,000. The proposed use of 10 m^3 rainwater tanks indicated the possibility of reducing the demand on reticulated potable supply by 60%. The Gold Coast Water study concluded the following benefits from the mandatory inclusion of rainwater tanks in its residential housing study:

- Decreased demand on the external water reticulation system.
- Decreased demand on the local storm water system and about 17% saving on downstream storm water management costs.
- Decreased downstream erosion.
- Decreased spread of pollutants.

In order to enhance the advantages of rainwater harvesting, it would be necessary to reduce the water demand. This will need the following:

- Water saving devices—water efficiency is promoted by the Australian government through the introduction of the national Water Efficiency Labeling and Standards (WELS) scheme, which has now become mandatory. This has led to improvements in shower heads, washing machines, toilets, dishwashers, taps, flow regulators and urinals.
- Water efficient gardens and gardening techniques—there are several water saving techniques that can be used to minimize the external use of water in residential housing such as the use of native plants that require less or virtually no additional water over natural rainfall, subsurface irrigation to minimize evaporation, deep layers of mulch to retain soil moisture and minimize evaporation, minimal areas of lawn and the associated need for watering, use of timers on taps used for garden watering, etc.
- Modifying occupants' habits—for example shorter showers, use of correct settings for both clothes washing and dish washing as well as operating with full or optimal load, etc.

Acceptance of Alternative Water Sources

The two key players, local authorities and the general public, both need to accept the adoption of alternative water sources. A market analysis by Mitchell et al. (2002) indicated that more than 90% of the community accepted the use of recycled water for garden and toilet flushing. This acceptance dropped rapidly when recycled water was proposed for clothes washing. Local authority acceptance of tanks as a source of potable water varies and is an issue which needs addressing if water tanks are to become a truly significant part of the housing water cycle.

The Brisbane City Council, where Brisbane Water operates the reticulated supply, used to assign rainwater as a high hazard product irrespective of the quality of stored rainwater. In contrast, the adjacent local authority of Ipswich allows the use of water tanks and assigns captured water as a low hazard product which is fit for human consumption with appropriate protection of its quality prior to storage. The Brisbane City Council now allows the regulated use of rainwater for garden watering and toilet flushing. This indicates that in the light of difficulties in supplying an adequate quantity of reticulated water, it is possible to promote rainwater harvesting as an acceptable option especially for gardening and toilet flushing with the possible inclusion of bathroom and laundry needs.

Components of a Rainwater System

A rainwater harvesting system consists of many basic components whose selection and integration need to be decided as part of the planning and design of the house. Therefore these components are described with respect to a display home where the actual system was installed and brought to successful operation. It is explained using the system installed in the largest house of three display homes that had a roof area of 290 m^2. The basic components include the following:

- The roof or collection surface.
- The gutters and gutter guards (Figure 1).
- Rain-heads, which are screening devices placed on each down pipe to deflect larger impurities from roof and gutter (Figure 2).
- Tank, which can be made of various materials such as concrete, galvanized or painted metal with a food grade internal plastic coating, polyethylene (Figure 3).
- First flush devices to divert a predetermined amount of water after a rain event commences (Figure 4).
- Pump to distribute the captured rainwater to the garden and/or house (Figure 5).
- Additional valves/screening/attachments for automated and/or integrated supply with reticulated town water.

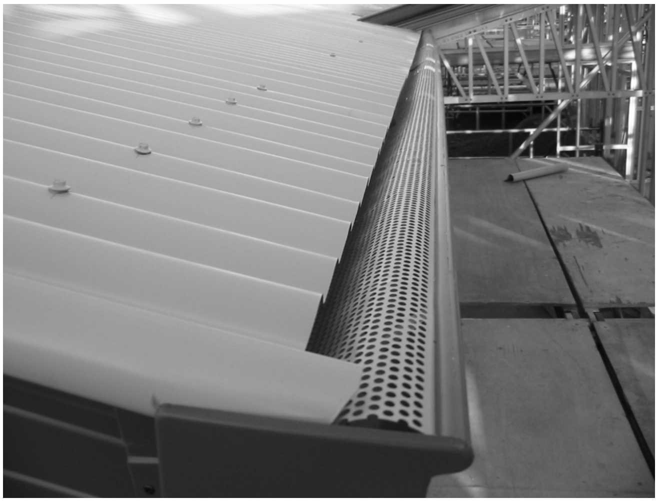

Figure 1: Roof and gutter guards used in a *Green Smart* display home.

Figure 2: A rain-head installed in a *Green Smart* display home.

Figure 3: Water tanks placed under the elevated floor of a *Green Smart* display home.

Figure 4: First flush device used in a *Green Smart* display home.

Figure 5: Pump and switching device used for uninterrupted water supply.

Capture Elements and Sizing

In large scale residential developments, the location for tanks may be constrained due to limited lot sizes as well as satisfying desired aesthetics. The selection of the optimum tank volume for rainwater storage based on rainfall averaged over many years is also a challenging task. Rainwater collection is certainly optimized by the fact that a roof and pipe system transfer almost 100% of the water falling onto the roof in times of low intensity rains. This fact gives rainwater tanks a distinct advantage over the standard runoff and dam collection system on which most reticulated town supplies rely.

For the selected *Green Smart* display home, two 6000 litre polyethylene tanks were selected (total storage capacity of 12,000 litres) considering various constraints imposed by the site (Figure 3). Roof, gutters and downpipes provide the necessary collection system which was made of stable components to allow uncontaminated water collection. Gutter guards (Figure 1), rain heads on downpipes (Figure 2) and first flush devices (Figure 4) are all additions that are becoming standard for maintaining the water quality in any rainwater collection system.

The gutter and the tanks can be arranged either as a dry system or a wet system. A "dry system" for rainwater collection involves down pipes leading directly into the storage tanks so that after a rain event, no water remains within the collection pipes. A "wet system" usually involves underground pipes before entering the storage tank and hence there is a possibility of contamination and breeding mosquitoes if the pipe entrances are not properly sealed. Since this water also needs to be flushed through the first flush device, a large capacity device will be required. For the *Green Smart* display homes, the dry system was used.

The sizing of first flush device can follow a simple equation based on the collection area and estimated pollution load on the roof. Zobrist et al. (2000) reports that the first one millimetre of rain would be able to reduce the concentration of dissolved substances significantly. Hence the first flush device can be selected to divert at least 1 mm depth of rainfall, and it could be even 0.5 mm when the pollution levels are insignificant. For the *Green Smart* houses, the first flush devices were sized to divert 0.5 mm depth of rainfall, since very little vegetation affected the houses which were also located at a long distance from any high volume major collector road. For a roof area of 290 m^2, 0.5 mm depth of water will need $290 \times 0.0005 \times 1000 = 145$ litres. Therefore, an 80 litre first flush device was placed before each of the 6000 litre tanks.

First flush devices have a slow release valve which allows the captured water to slowly drain to garden or storm water outlet and thereby empty and be ready for the next rain event. Contaminants are flushed from the roof and gutter into the device which closes mechanically when full, allowing the remaining roof water to flow into the tank. The release of the first flush water commences immediately the device receives water and the study by Miller et al. (2003) showed that this release rate can be significant to the efficiency of the storage system. The Healthy Home on the Gold Coast in south east Queensland, initially incorporated a release rate of 60 litres/hour which led to a catch efficiency of only 62%. Catch efficiency is the term used to indicate the ability of the system to capture the water falling on a roof after allowing for any losses in the roof system and the first flush device. If the leakage rate was reduced to two litres/hour via a smaller diameter drain hole, the catch efficiency would have improved to 87%.

Pumping of Water

The water tanks of the *Green Smart* display homes were located below the elevated ground floors as shown in Figure 3. Since the original land was sloping, the ground floors were constructed as elevated floors to minimize the cut and fill operation and potential erosion of natural soil. This gave sufficient space for locating the tanks with minimum impact on aesthetics. In order to provide water into the house from the tanks located at a lower elevation, a 1.1 kW pressure pump was used. This was intended to supply all internal uses and also drive an automated controller system which directed tank water to the sub-surface irrigation pipes at pre-selected times on selected nights, to minimise evaporation.

One disadvantage of rainwater tanks is the greenhouses gas impacts associated with the pumping of water from the tanks. Significant energy is consumed at pump start up and also at very low flows (toilet cistern filling). Therefore, less pump start ups via the use of a larger volume pressure vessel or the use of elevated tanks may significantly improve pump efficiency.

Integration with Town Water

In order to ensure continuous and automated supply of water, a unique system was adopted that allowed automatic switching between the tank water and the pressured town water. This switching system (Davey, 2005) allows the town water to pressure the whole house when the tank water has reached a preset low threshold or when there is a power failure to the pump. The device switches back to the tank supply when rain has replenished sufficiently above the threshold level. This system, which guarantees continuous water supply, was accepted by the Ipswich City Council plumbing department with the added requirement of back-flow prevention device at the boundary connection to the town supply system. Figure 6 shows a schematic diagram of the system.

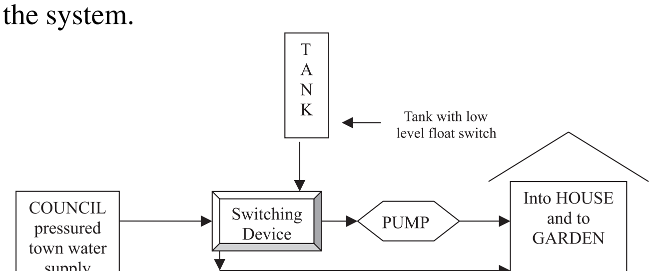

Figure 6: Water supply system with switching device to allow town water use when the tank water levels are low.

Water Saving Potential

An important estimate needed for assessing the expected performance of a rainwater harvesting system is the volume of water that can be supplied as captured rain water. This is a difficult parameter to estimate since the rainfall patterns and the usage can vary. However, it would be possible to make an approximate estimate of this by using the average rainfall data available. The average rainfall for each month in Ipswich area is given in Table 2, along with the mean number of rain days obtained based on past records by Bureau of Meteorology (BOM, 2004). This data allows the determination of average rainfall per day. This can lead to an approximate volume of water that is captured in each rain event. Since it is not possible to capture all the water that will fall on the roof, a suitable catch efficiency should be used. This will allow taking account of water lost due to first flushing device when low intensity rainfalls occur more frequently. For this estimate, a catch efficiency of 70% was used since previous studies indicate values varying between 62% to 87% (Millar et al., 2003). This means, a volume equivalent to 30% of the rain water falling on the roof will be lost due to the first flush device or tanks being full.

Another important parameter that can affect the amount of rainwater captured is the water usage. Two different water usage values were assumed, being 800 l/day for hot months and 600 l/day for cold months. Such different usage values were observed by Herrman and Schmida (1999) in their actual monitoring of the water usage in a typical house in Germany. The selected values are slightly higher than the value of 595 l/day obtained from Healthy Home (Gardner et al., 2003; 2005). However, they are lower than the average usage of 1000 l/day, generally used in Australia. The above values would be realistic considering the fact that a number of water saving devices have been installed in the display homes.

The roof area of the display home under consideration was 290 m^2. The town water requirement is calculated on monthly basis in Table 2. Any excess water from the previous month was also ignored. The estimated total usage per annum was 255 m^3. The water collected as rainwater is about 168 m^3. This means that the percentage of town water required could be reduced to about 35%. This indicates that water saving efficiency of 60-70% could be expected in an average house located in Ipswich, which generally has relatively low annual rainfall of about 880 mm and also few consecutive months of low rainfall intensity such as about 50 mm per month.

It can be seen that the above calculation is only an approximate indication of the water saving potential. A more accurate method was presented by Fewkes (1999b) based on actual measurements made with different rainfall patterns. However, that method was not used since it would need more accurate rainfall patterns, preferably at a lower interval such as daily or weekly variations.

The Cost Aspects

There are two main cost components, namely, the initial system components (capital cost) and the on-going pump energy, system maintenance and replacement cost

Table 2: Tank storage and household use calculations for a display home

LOT 894	*Days*	*Average rainfall mm*	*Mean number of rain days Days*	*Average per rain day mm*	*Volume from roof per rain day m^3*	*Volume after losses m^3*	*Monthly stored volume m^3*	*Usage per day l/day*	*Predicted house hold usage m^3*	*Town water top up m^3*
Jan	31	124.6	9.9	12.6	3.66	2.56	25.3	800	24.8	-
Feb	28	119.8	10.0	11.9	3.45	2.42	24.2	800	22.4	-
Mar	31	100.6	10.3	9.8	2.84	1.99	20.5	800	24.8	4.3
April	30	63.1	7.8	8.1	2.35	1.65	12.9	600	18.0	5.1
May	31	50.5	6.7	7.6	2.21	1.55	10.4	600	18.6	8.2
June	30	51.1	5.2	9.8	2.84	1.99	10.4	600	18.0	7.6
July	31	43.5	5.3	8.2	2.38	1.67	8.8	600	18.6	9.8
Aug	31	33.0	5.0	6.6	1.92	1.35	6.8	600	18.6	11.8
Sept	30	41.5	5.6	7.4	2.15	1.51	8.5	600	18.0	9.5
Oct	31	65.7	7.4	8.9	2.58	.181	13.4	800	24.8	11.1
Nov	30	77.7	8.1	9.6	2.78	1.95	15.8	800	24.0	8.2
Dec	31	106.1	9.0	11.8	3.42	2.39	21.5	800	24.8	3.3
Total	365						168.1		255.4	78.9

(operational cost). The average capital cost for system components for the three display houses was $6,300. This included gutter guards, rain heads, first flush devices, tanks, pump, switching device and additional labour. Since the display homes will not be occupied for some time, it is not possible to obtain the actual pump operational cost. Therefore, the actual values from Healthy Home (Gardner et al., 2003) were used. The electricity charges were calculated at 1.2 hours of operation per day for 365 days for a 1.1 kW pump at $0.14 per kWh. The 1.2 hour operation includes the continuous pump operation for both internal and external uses consisting of showers, toilet refilling, clothes and dish washing, kitchen uses, hand basins, car washing and garden irrigation. The annual maintenance cost was estimated as $35.00. This gives a total of $102 where $67.00 is allocated for pump operation ($1.2 \times 1.1 \times 365 \times 0.14$). The amount of water saved is 168 m^3 and at the current rate of $0.62/$m^3$ results in a saving of $104.00. Thus, there is a resultant saving of only $2.00 indicating that with present tariff structure for reticulated town water supply, there is no chance of recovering the cost of installation. However, there are several factors that can turn this scenario in favour of rainwater harvesting:

- Recent years have seen a steady rise in the cost of water. Also, excess water usage is being penalized with Ipswich City Council currently charging $1.30/$m^3$ for the usage above 150 m^3 per month. Such values can allow at least partial recovery of the capital cost.
- Increased sales of tanks and associated components would create a downward cost due to normal market forces and increased competition.
- Government grants in recognition of reaching at least partial self sufficiency in water usage are continuing and showing support for the future sustainability of large scale housing developments.
- Use of solar or other renewable power for water pumping coupled with the possible use of an overhead tank to optimize the pumping operation.

Conclusions

The responsibility rests with house design professionals, industry groups, government and the general public to improve on the number of features included in houses that will promote sustainable development principles. In this context, rainwater harvesting could be promoted to reduce the reliance of reticulated supplies and improve sustainability of water use.

A fully automated rainwater harvesting system that was integrated with town water supply in three display homes has given many insights into the planning, construction and operational challenges that may be encountered with large scale housing projects. The system implemented included quality controlling measures such as adoption of a dry system, first flush devices, gutter guards and rainheads. The tanks were located below the elevated ground floor level on a sloping ground, and thus the impact on aesthetics was minimised

The size of the storage tanks and the rainwater patterns will have a major impact on the portion of the annual water consumption that can be supplied with rainwater. For the analysed display home, it was estimated that 12 m^3 capacity tanks, combined with the use of water saving devices, could provide reticulated water savings of about 60-70%. However, this was associated with a significant initial cost of $6300.00 for incorporating water quality devices, rainwater tanks, a pressure pump and a specialist switching device to link pressured town water into the system. The experience showed that the successful integration of a rainwater and reticulated pressure system needs planning at the design and construction stages to provide an efficient integrated system.

With the present water tariff structure, it is not feasible to recover the initial capital cost of a fully integrated tank system on houses within large housing estates. This is unfortunate given that rainwater tanks are very efficient at capturing rainwater. This study also identifies that increased efficiencies are possible with reduced energy use for water pumping. Changing water pricing and more frequent droughts will possibly change this scenario. There are also other advantages to the adoption of rainwater tanks including the reduction of stormwater impacts and pollutants entering waterways and reduced downstream erosion.

The broad scale introduction and acceptance of rainwater tanks is likely to need wide community consultation and education, combined with significant government and industry support.

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References

Australian Bureau of Statistics, AustStats (1997). Water Account for Australia 1993-94 to 1996-97, www.abs.gov.au/austats

BOM (2004). Ipswich average climate statistics. Bureau of Meteorology. Web site visited 11 April 2005, www.bom.gov.au/climate/averages/tables/cw_040101.shtml

Cunliffe, D. (2004). Guidance on the use of rainwater tanks. National Environmental Health Forum Monographs, Health Council, Water Series No. 3, 29 pages.

Davey (2005). "Rainbank" switching system. Davey Products Pty Ltd. Web site visited 12 April 2005, www.davey.com.au/rainbank/index.html

DPW (2005). Queensland Department of Public Works. Research House, web site visited 9 April 2005, www.build.qld.gov.au/research/library/index.asp

Fewkes, A. (1999a). The use of rainwater for WC flushing: The field testing of a collection system. *Building and Environment*, **34:** 765-772.

Fewkes, A. (1999b). Modelling the performance of rainwater collection systems towards a generalized approach. *Urban Water*, **1:** 323-333.

Gardner, T., Millar, G. and R. Hyde (2003). The Healthy Home: A step towards sustainable suburbs. Proceedings of the 2nd National Water Recycling Conference, Brisbane, September 2003. Australian Water Association and Stormwater Industry Association, September, 2003.

Gold Coast Water (2004). Pimpama Coomera Waterfuture – Master Plan Report. Gold Coast City Council. March, 2004.

Healthy Home (2005). Queensland Department of Natural Resources and Mines and Environmental Protection Agency. Healthy Home Project, web site visited 13 April 2005, www.healthyhomeproject.com

Herrman, T. and U. Schmida (1999). Rainwater utilization in Germany: Efficiency, dimensioning, hydraulic and environmental aspects. *Urban Water*, **1:** 307-316.

Millar, G., Bofu, Y. and T. Gardner (2003). Rainfall catch efficiency for domestic water supply, 28th International Hydrology and Water Resources Symposium by The Institution of Engineers, Australia, Wollongong, NSW. November, 2003.

Mitchell, G.V., Shipton, R.J. and S.R. Gray (2002). Assessing innovative urban water servicing options for a greenfield development site. *Australian Journal of Water Resources*, **7(2):** 139-154.

Zobrist, J., Muller, S.R., Amman, A., Bucheli, T.D., Mottier, V., Ochs, M., Schoenenberger, R., Eugster, J. and M. Boller (2000). Quality of Roof Runoff for Groundwater Infiltration. *Water Resources*, **34(5):** 1455-1462.