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Rainwater Harvesting in Large Residential Buildings in Australia

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1. Introduction

Australia is one of the driest inhabited continents, with highly variable rainfall. A growing urban population and frequent droughts in recent years have made water supply a major issue in Australia. A number of alternative water sources have received attention in Australia including rainwater harvesting, grey water reuse and wastewater recycling. Among these, rainwater harvesting has received the greatest attention as rainwater is fresh in nature and can be easily collected and used for non-potable purposes. However, many Australians still show a reluctance to adopt rainwater harvesting systems. Statistics from the Australian Bureau of Statistics (ABS) show that about 47% of respondents say that the main reason for not installing a rainwater tank is the perceived 'higher cost' (ABS, 2011). Government authorities in Australia provide financial incentives to encourage home owners to install rainwater tanks. For example, Sydney Water Corporation in Australia offers a rainwater tank rebate of up to $1,500 (here $ is in Aus$) depending on the size of the tank installed and the type of water use.

Many home owners do not readily see the benefit of a rainwater harvesting system over the long term, which may be attributed to the limited understanding of the life cycle costs of the system. Domenech and Sauri (2010) investigated the financial viability of rainwater harvesting systems in single and multi-family buildings in the metropolitan area of Barcelona (Spain). In single-family households, an expected payback period was found to be between 33 to 43 years depending on the tank size, while in a multi-family building a payback period was 61 years for a 20 m^3 tank. Imteaz et al. (2011) found that for commercial tanks connected to large roofs in Melbourne, total construction costs can be recovered within 15 to 21 years depending on the tank size, climatic conditions and future water price increase rate. Tam et al. (2009) investigated the cost effectiveness of rainwater harvesting systems in residential areas around Australia and found that these systems can offer notable financial benefits for Brisbane, Sydney and the Gold Coast due to the relatively higher rainfall in those cities as compared to Melbourne.

Notable research has been conducted on the relationship between rainwater tank sizing and water savings. Khastagir and Jayasuriya (2009) used water demand and roof area to develop a set of dimensionless number curves to obtain the optimum rainwater tank size for a group

of suburbs in Melbourne. A paper by Ming-Daw et al. (2009) focused on the development of a relationship between storage and deficit rates for rainwater harvesting systems. Results showed that as the deficit rate increased so too did the storage size of the tanks. Eroksuz and Rahman (2010) conducted research on the use of rainwater harvesting systems for multi-unit blocks in three cities of New South Wales (NSW), Australia. They found that in order to maximise water savings, larger tanks would be more appropriate and these tanks could provide significant water savings, even in dry years. A study in Brazil by Ghisi et al. (2009) aimed to assess the potential for potable water savings for car washing at petrol stations in the City of Brasilia found that an increase in the tank size enhanced the reliability of the rainwater tank notably in meeting demand. Kyoungjun and Chulsang (2009) showed that rainwater collection would only be feasible in South Korea during six months of the year. They also found that increased cost and marginal increase in reliability make larger tanks unsustainable. They also found that a benefit cost ratio higher than 20% could not be gained due to the low cost of water in South Korea. They suggested the cost of water supply would need to be increased by a factor of five for the rainwater harvesting system to become economically viable in South Korea.

There is often a lack of 'easy to use' computing tools which examine the viability of rainwater harvesting system in large buildings. The financial viability of a rainwater harvesting system depends on factors such as local rainfall, roof size, water demand, capital cost, interest rate, maintenance cost and mains water price. This chapter presents a computing tool that can be used to examine various scenarios of a rainwater harvesting system to compare water savings and financial benefits based on life cycle cost analysis. The first part of the chapter presents the computing tool followed by a case study illustrating the use of the computing tool and the associated results.

2. Rainwater Tank Analysis Model

A computer model, which is referred to as the Rainwater Tank Analysis Model (RWTAM) is presented here. The RWTAM can be used to examine the water saving potential and financial viability of a rainwater harvesting system in multi-storey residential buildings. The RWTAM can provide a wide range of results for a proposed rainwater harvesting system including the major cost and benefit elements.

The RWTAM is Windows-based and was developed using Visual Basic. It has various input and output interfaces to enter data and obtain results on water savings and costings of a proposed rainwater harvesting system. The program has 5 main menus: File, Water Savings, Cost Analysis, Settings and Help. Each of these menus has a number of sub-menus as shown in Table 1.

A 'continuous simulation type' water balance model based on daily time steps is used in the program, which calculates the inflow to and outflow from the rainwater tank based on water demand and rainfall data on a given day. The water demand is assumed to consist of toilet flushing, laundry, car washing and irrigation demand. The irrigation demand is difficult to estimate. This is due to the fact that on the days of rainfall and possibly on a number of subsequent days after a significant rainfall event, the irrigation demand would be nil or would be smaller than a normal dry day. In order to account for this, the following approximate but simple procedures are adopted: (i) For 1 day of rainfall, there would be no

Main menu	Submenu	Function	Description
File	Open Rainwater Data File	This allows the user to select the relevant daily rainfall data file for the study area.	The daily rainfall station's data from the study area is needed.
	Exit	This allows the user to exit the program.	Exit the program.
Settings	RWTAM Input	This allows the user to enter data (for calculating rainwater savings) such as lot size, roof area, number of occupants and water demand.	Example in Figure 1.
	LCCA Input	This allows the user to enter various input data for cost analysis such as capital cost, government rebates and installation costs.	Example in Figure 2.
Water savings	Annual Water Savings	This function produces an average annual water savings vs. tank size plot as shown in Figure 3.	Tank sizes covered range from 10 kL to 100 kL. Example in Figure 3.
	Annual Water Savings	This function presents the annual average water savings in kL for each tank size.	This helps to interpret the results.
	Yearly Water Savings	This function produces a text file containing water savings achieved for a given tank size.	User needs to select a particular tank size.
Cost analysis	Benefit Cost Ratio (BCR)	For a selected tank size, this function gives a BCR which considers the whole life cycle of the rainwater harvesting system.	If the BCR > 1, the rainwater harvesting system presents a net saving.
	Breakdown of Life Cycle Costs	This function produces an output windows showing the cost for each of the major categories.	Example in Figure 4.
	Breakdown of Capital Cost	This function produces an output windows showing costs for each of the major categories: rainwater tank, concrete base, pump (indoor), pump (outdoor), accessories, plumping cost, electrical costs and governement rebates.	Example in Figure 5.

Table 1. Main menus and submenus of RWTAM model

irrigation during the day but irrigation would resume on the next day. (ii) For 1 to 7 days of consecutive rainfall, there would be no irrigation during the rainfall days plus none for the equal number of previous days of consecutive rainfall. (iii) For 8 to 21 days of consecutive

rainfall, there would be no irrigation during the rainfall days plus no irrigation for the equal number of previous days of consecutive rainfall up to 7 days. The water demand on a particular day is then calculated by adding the indoor demand, car washing demand and the required irrigation (garden and lawn) demand for the day.

From the water balance model, the following output values are estimated on a daily basis: (i) net rainfall entering into the tank (ii) water in the tank (ii) water demand (iii) mains top-up and (iv) water savings. The mains top-up is the amount of mains water needed to top-up the rainwater tank to the specified minimum level (e.g. 10% of the tank volume). For the cost analysis, RWTAM undertakes life cycle cost analysis (LCCA), which is the procedure of assessing the cost of a product over its life cycle or portion thereof (AS/NZS, 1999). The life cycle cost is the sum of acquisition and ownership of a product over its life cycle (AS/NZS, 1999). All past, present and future cash flows identified in the LCCA are converted to present day dollar value and are a function of discount rates. All costs considered here are in Australian dollars. This study uses the concept of nominal cost (the expected price that will be paid when a cost is due to be paid, including estimated changes in price due to changes in efficiency, inflation/deflation, technology and the like) and nominal discount rate (the rate to use when converting nominal costs to discounted costs). To convert a nominal cost (C_N) to discounted cost (C_D), following equation is used (AS/NZS, 1999):

$$C_D = C_N \times \left(\frac{1}{(1+d_n)^y} \right) \tag{1}$$

where d_n is the nominal discount rate per annum and y is the appropriate number of years.

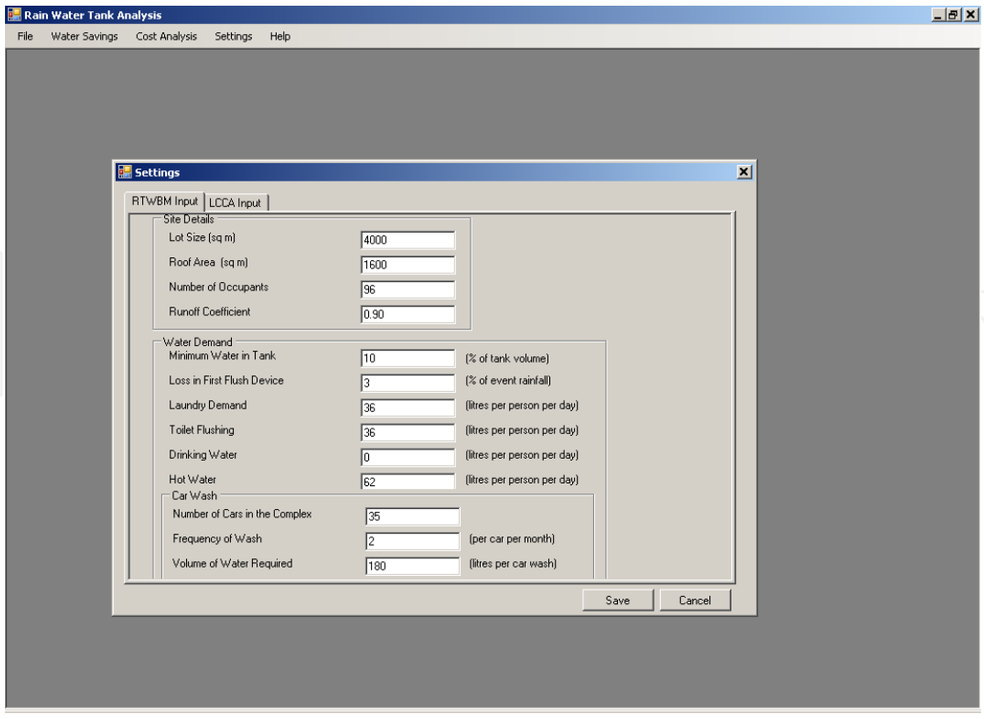


Fig. 1. Input interface of the RWTAM program for water savings

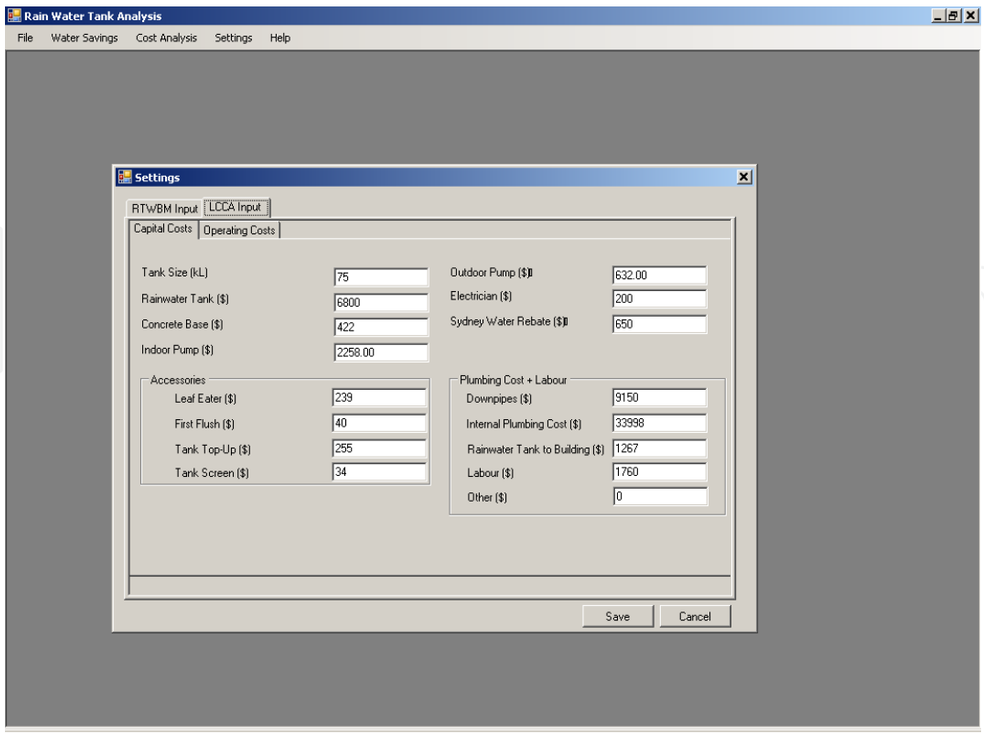


Fig. 2. Input interface of RWTAM program for life cycle cost analysis

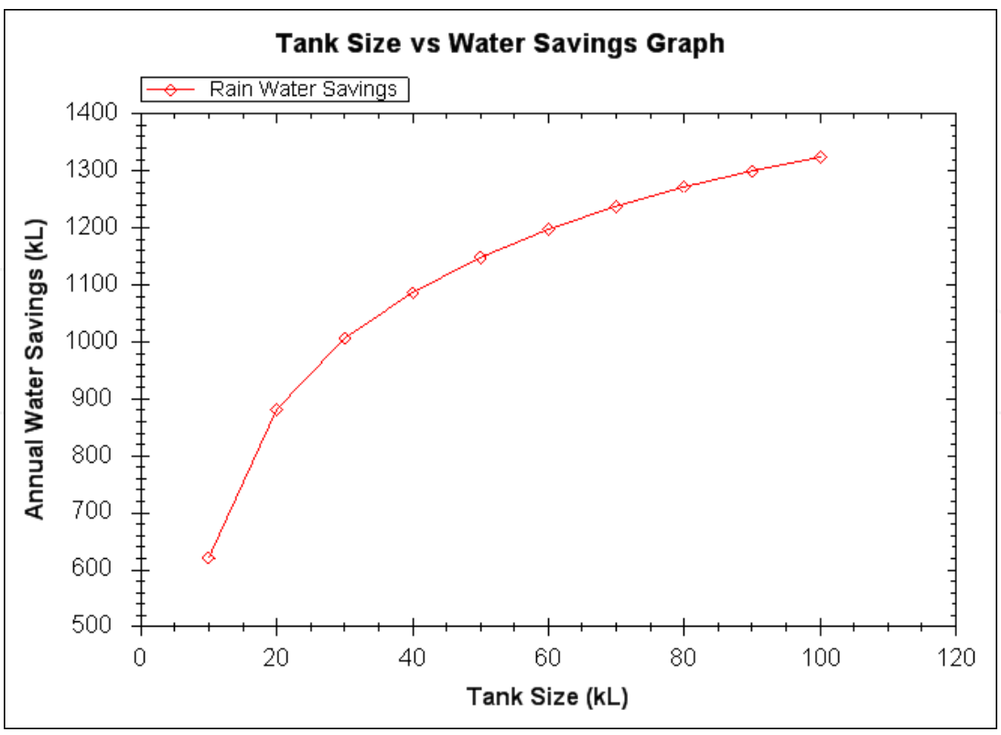


Fig. 3. Average annual water savings graph as an output from the RWTAM program

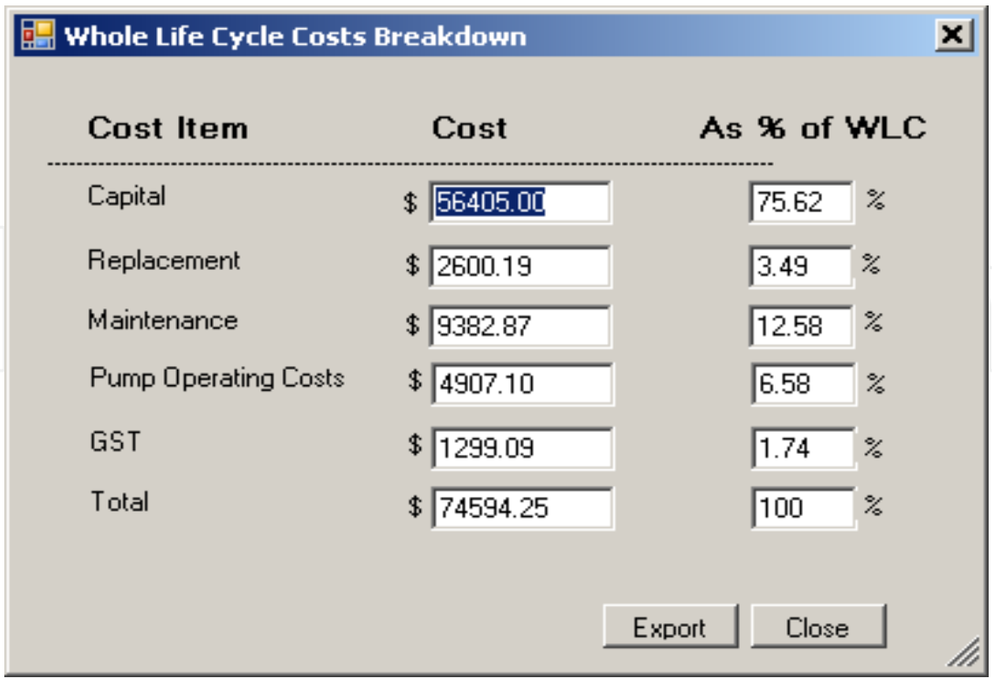


Fig. 4. Whole life cycle (WLC) cost breakdown as an output from the RWTAM program

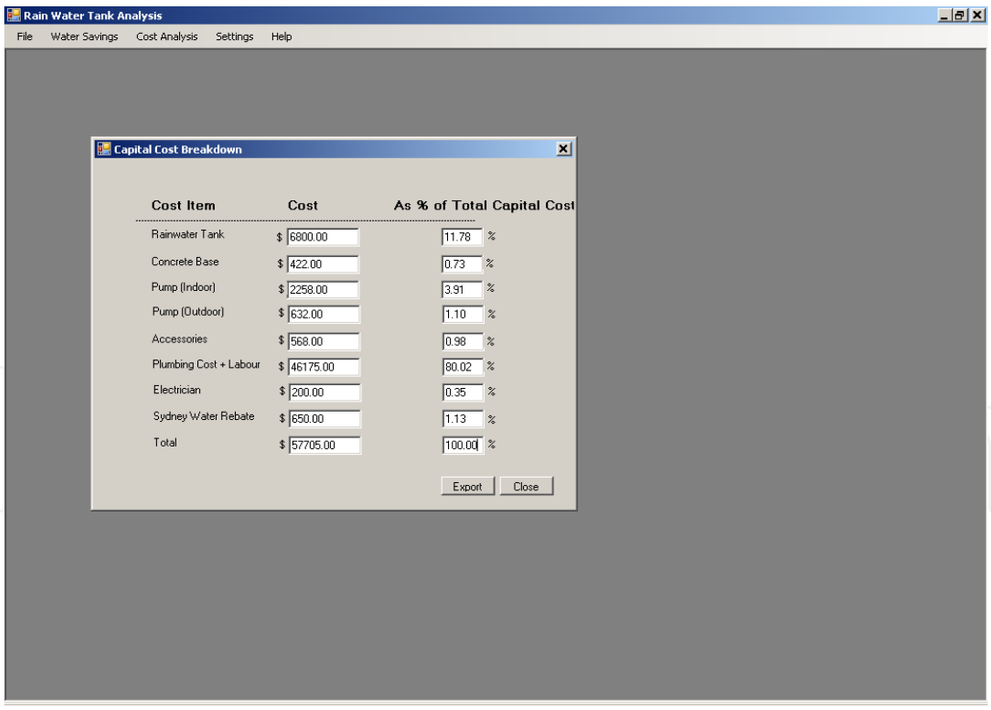


Fig. 5. Breakdown of capital cost as an output from the RWTAM program

The various steps involved in running the RWTAM are as follows. (a) Install the program in a local directory called 'Rain Water' (b) Open the program by double clicking on the 'Rainwater Tank' icon. (c) Open the rainwater data by going to the 'File' icon and selecting

the daily rainfall data file relevant to the multi-storey building site in question. (d) Select 'Setting menu' and enter the data for Rainwater Tank Water Balance Model and LCCA. (e) Obtain output/results on water savings and cost analysis selecting the 'Water Savings' and 'Cost Analysis' icon, respectively. The various menus and submenus are self-explanatory and easy to work with.

3. A case study in Sydney Australia

An example is presented here to illustrate the application of the RWTAM. For this example, a hypothetical multi-storey building is considered, located in the Botany Bay Council area in Sydney, Australia. Daily rainfall records over 60 years (Jan 1946 to Dec 2005) from Sydney Airport station are used. A 75 kL tank size is selected for the purpose of this case study. Two different site areas are considered: 2000 m^2 and 4000 m^2 with roof areas of 800 m^2 and 1600 m^2 respectively. For each of these two site areas, three different floor arrangements are considered assuming four apartments per floor and 3 persons per apartment: (a) 4 floors consisting of 16 apartments having 48 persons (b) 6 floors with 24 apartments having 72 persons (c) 8 floors with 32 apartments having 96 persons. In the life cycle cost analysis (LCCA), it is assumed that the rainwater harvesting system has a life of 60 years.

According to the Building Sustainability Index (referred to as BASIX) for multi-unit buildings, all new houses in the state of New South Wales (NSW) must save at least 40% of potable water as compared to an average traditional non-BASIX house (NSW Department of Planning, 2005). This involves rainwater harvesting, the use of various water efficient appliances in the apartment such as 4A rated washing machines and dishwashers, 3A rated dual flush toilets (the higher the A-rating, the more water efficient the device is), water efficient shower heads and taps and native, low-water-use plants. Both BASIX and non-BASIX (i.e. traditional) approaches with rainwater harvesting systems are examined in this case study. It is assumed that rainwater is used for toilet flushing and laundry (indoor water use) and irrigation (garden and lawn); the relevant water demand data is obtained from Sydney Water Corporation.

In the water balance model, the effective runoff is generated by calculating the precipitation minus the losses which are the runoff coefficient and first flush losses. A plot of the annual precipitation is shown in Figure 6 which shows a notable variability of total rainfall from year to year and also a drop in total rainfall values from 1991 to 2005. However, annual total rainfall values may not have direct influence on the water yield of rainwater tanks which is mainly governed by distribution of rainfall events in a year and magnitude of rainfall events. For example, if the event rainfall is too high, most of the runoff will leave the rainwater tank as overflow as the tank would overflow very quickly.

The building area or the catchment area is assumed to be 40% of the total site area, which forms the tank footprint. The loss arises from gutter overflow, evaporation and first flush. It is assumed here that one litre of water is diverted to first flush per square metre of roof area. Once the first flush device is full, the remaining rainwater is diverted to the rainwater tank. Therefore the first flush losses are 800 litres for the 800m^2 roof and 1,600 litres for the 1,600m^2 roof. The total losses as a component of the runoff for each of the roof areas are presented in Figures 7 and 8. It can be seen in Figures 7 and 8 that the total losses increase

with the runoff generated. For this scenario, the loss generated from the 800m² roof is exactly half of that generated by the 1,600m² roof. The runoff coefficient is assumed to remain constant throughout the life cycle analysis period, which is assumed to be 60 years.

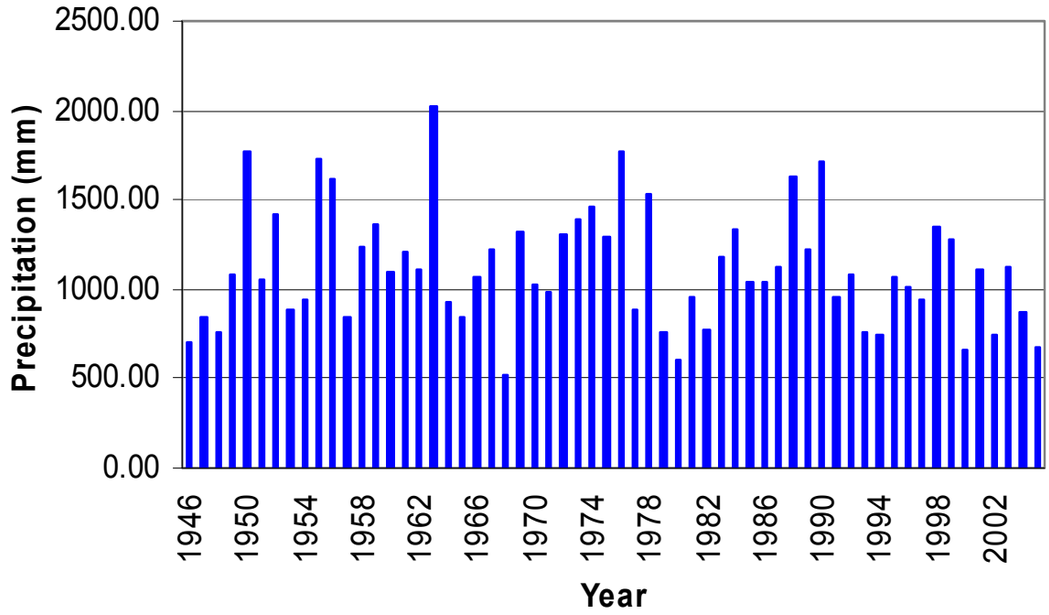


Fig. 6. Variability in annual precipitation values from 1946 to 2005 at Botany Bay (Sydney)

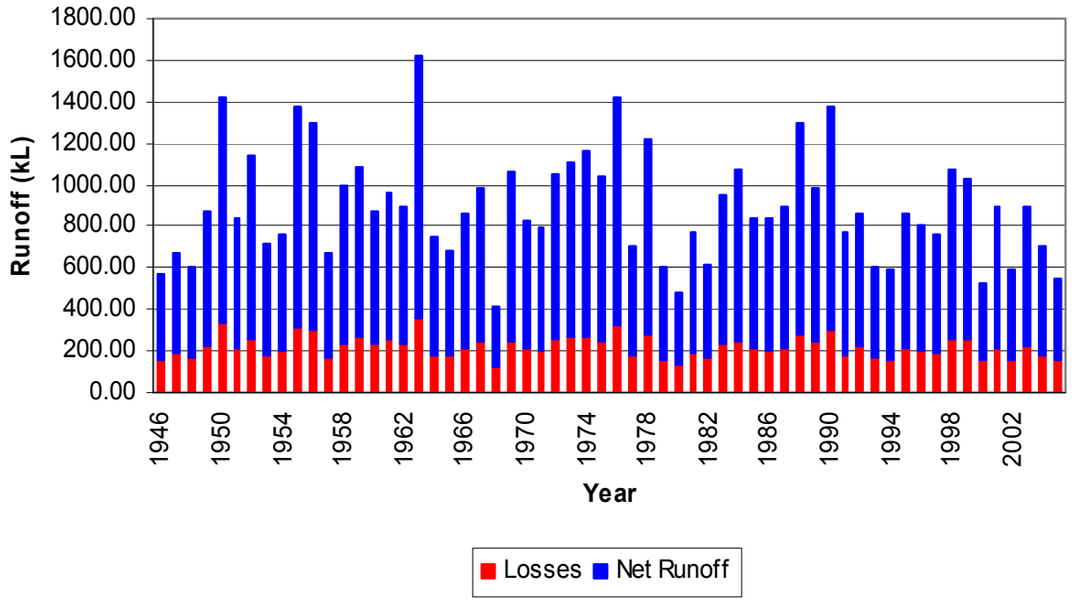


Fig. 7. Loss and runoff (2,000m² site area)

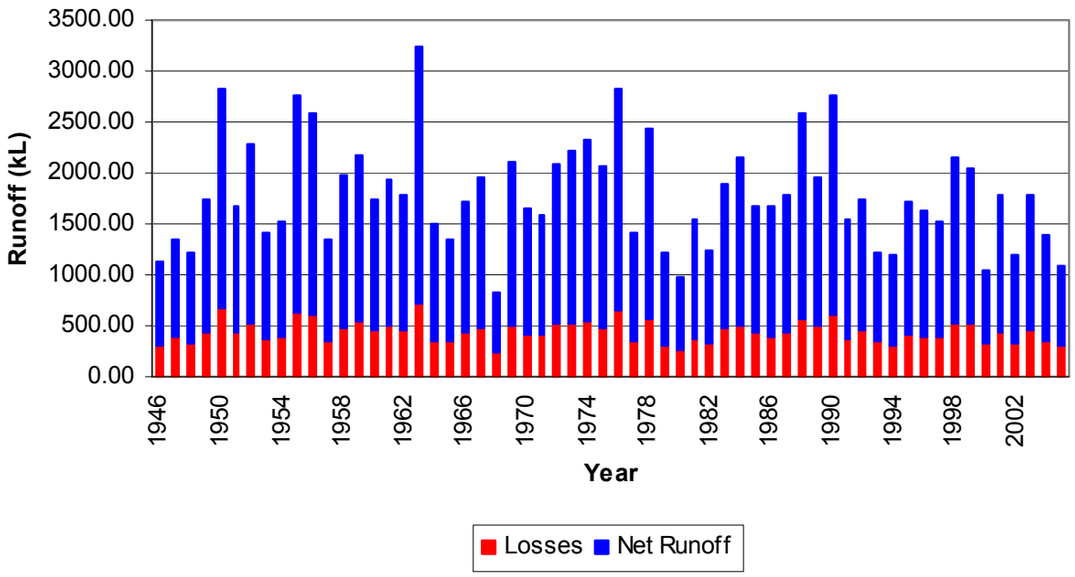


Fig. 8. Loss and runoff (4,000m² site area)

Figure 9 illustrates the difference between the effective runoff generated from the two roof areas, with the 1,600m² roof generating twice the runoff of the 800m² roof area. It can also be seen that the runoff is directly proportional to the rainfall.

In order to assess how much water is available per year in relation to the water demand, four graphs representing different scenarios are presented in Figures 10 to 13. The water available is the effective runoff entering the tank minus the overflows. It can be seen in Figure 10 that the water available (or the net water entering the tank) exceeds the water demand for more than half of the years out of the sixty years analysed. This does not mean that no mains top-up is required as the rainfall can happen in large storm events resulting in greater tank overflow. With an increased water demand relating to the six-floor scenario, the water available only exceeds the water demand for a few of the sixty years and only exceeds the water demand once for the eight-floor scenario.

As the water demand keeps on increasing, the water available cannot keep up and mains top-up is required. Ironically, the higher water demand means that more mains top-up needs to be used which results in higher water savings. It can be seen from Figure 11 that the water availability exceeds the water demand only once for the four-floor scenario. The six-floor and eight-floor scenarios require mains top-up every year.

It can be seen in Figure 12 that with the larger site area (i.e. 4,000m²), despite the increased irrigation demand, the water availability far exceeds the water demand for the majority of the years for the four and six floor scenarios. In fact, the water availability exceeds the water demand for all but two years for the four floor scenario. Only twelve years miss out for the six floor scenario and about half the years for the eight floor scenario. Figure 12 shows the advantage of having a larger roof area to capture a greater amount of rainfall into the tank.

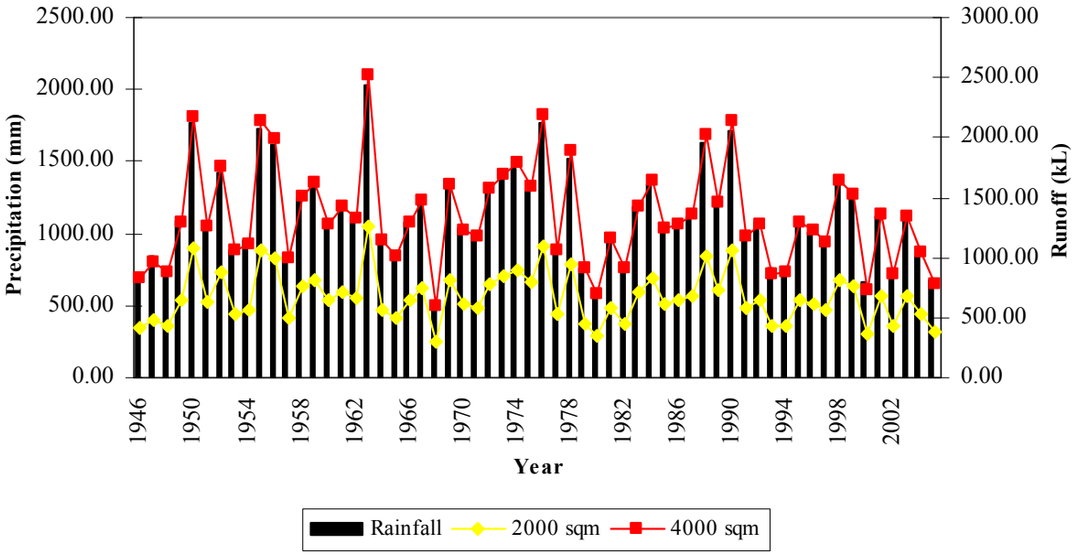


Fig. 9. Comparison of effective runoff for two roof areas

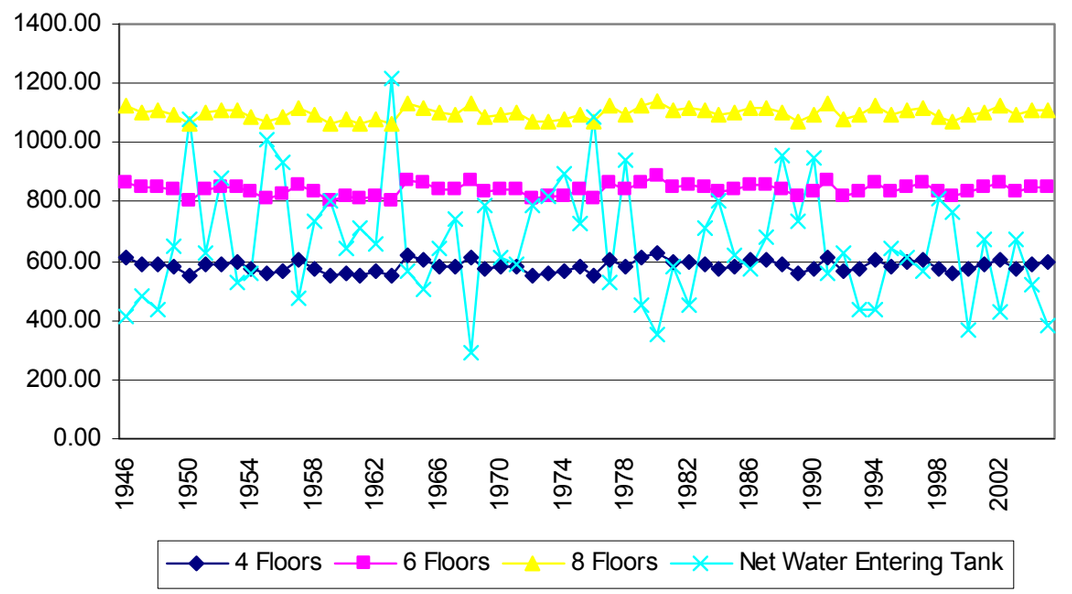


Fig. 10. Water entering tank vs. water demand (BASIX and 2,000m^2 site area)

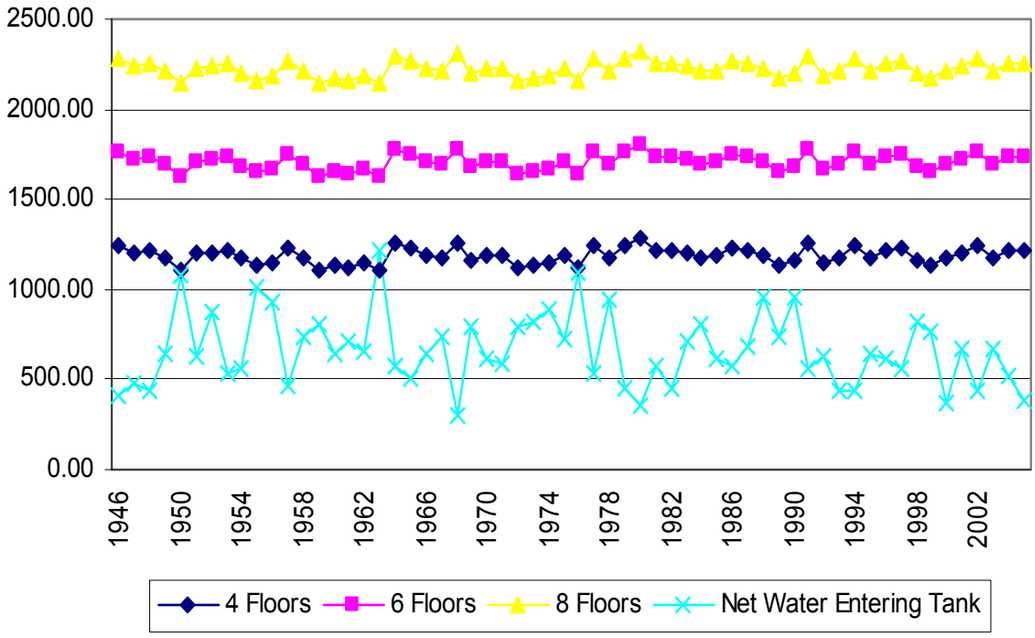


Fig. 11. Water entering tank vs. water demand (Non-BASIX and 2,000m² site area)

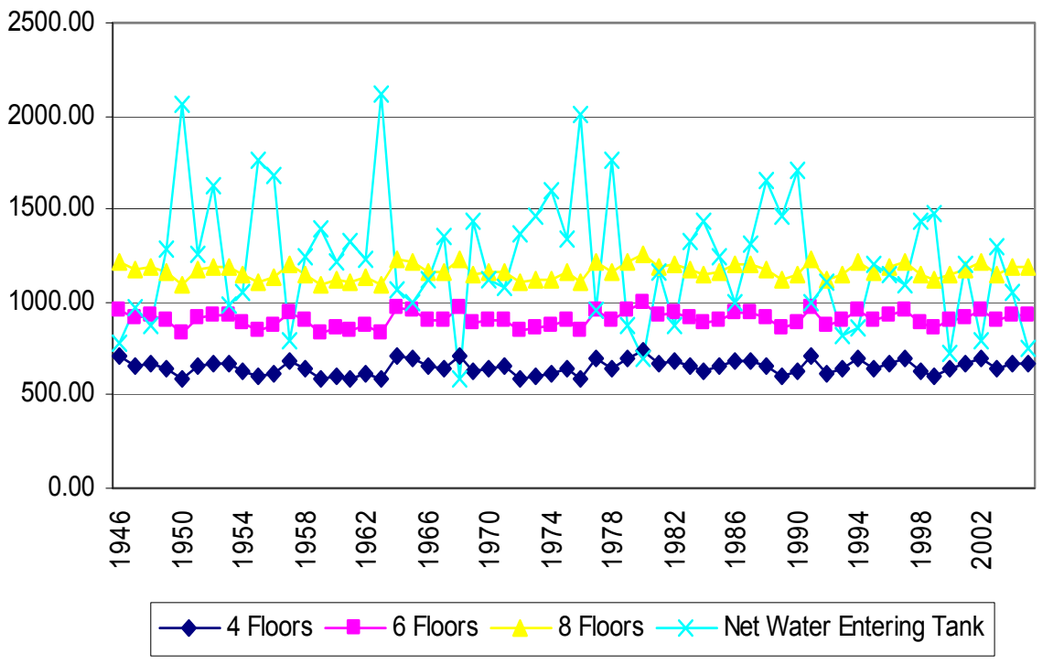


Fig. 12. Water entering tank vs. water demand (BASIX and 4,000m² site area)

Figure 13 shows that as the water demand increases, the water availability is unable to meet the demand. Despite the larger roof area, the water availability exceeds demand for about eighteen of the total sixty years for the four-floor scenario. The water availability exceeds demand only twice for the six floor scenario and none for the eight floor scenario.

The average mains top-up required per year over the sixty year analysis period is shown in Figures 14 to 17. It can be seen that the mains top-up required increases with the water demand, with the eight floor scenario requiring significantly more mains top-up than the four and six floor scenarios. There is also a significant difference in the mains top-up required between the BASIX and non-BASIX approaches. It is also noted that the mains top-up required decreases when the roof area is increased as a result of the increased runoff entering into the rainwater tank.

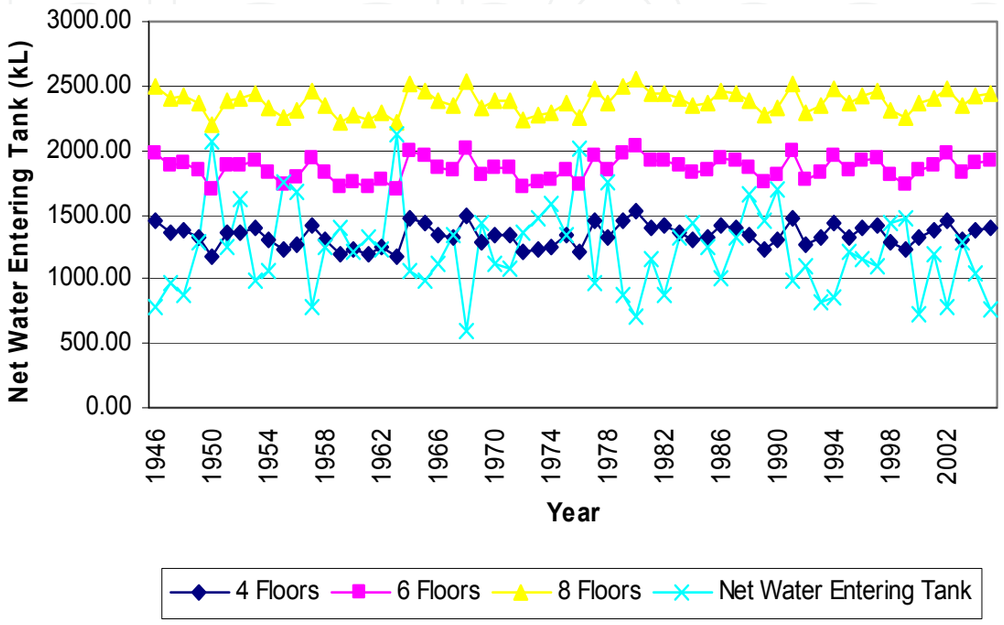


Fig. 13. Water entering tank vs. water demand (Non-BASIX and 4,000m² site area)

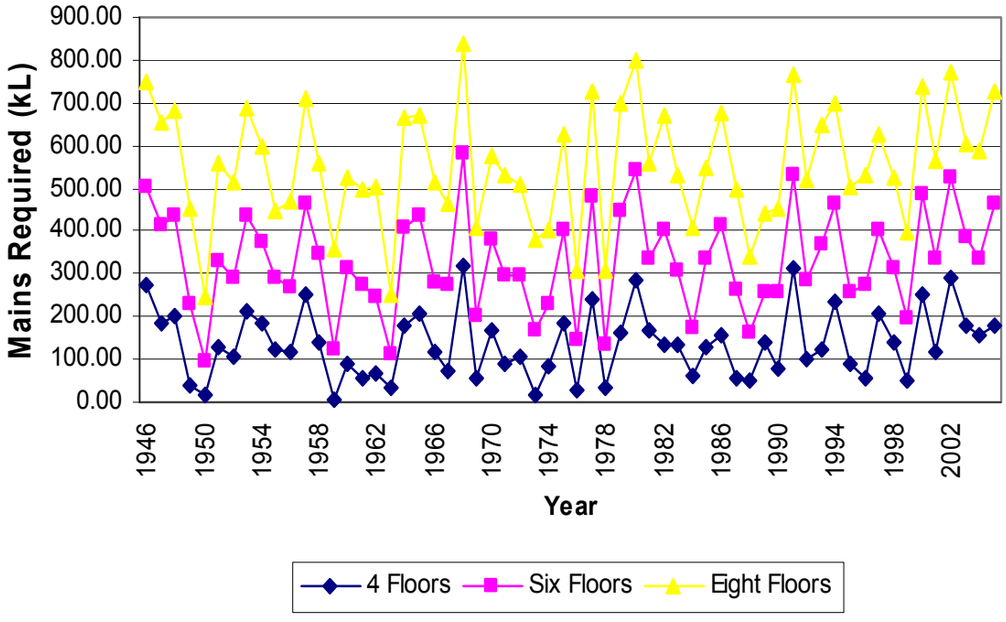


Fig. 14. Mains top-up required vs. water demand (BASIX and 2,000m² site area)

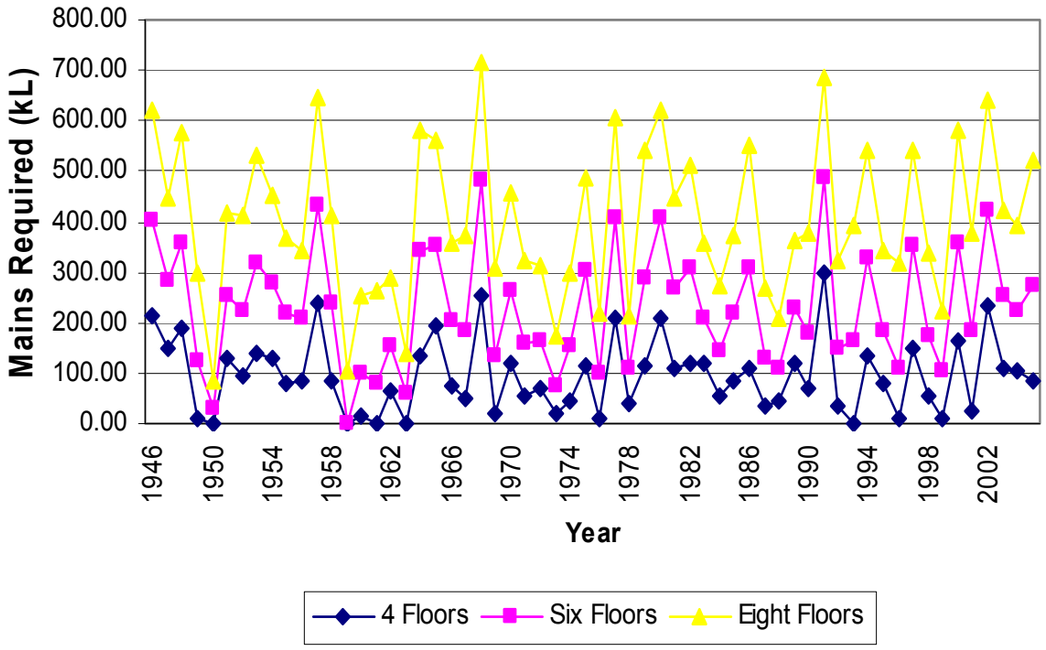


Fig. 15. Mains top-up required vs. water demand (BASIX and 4,000m² site area)

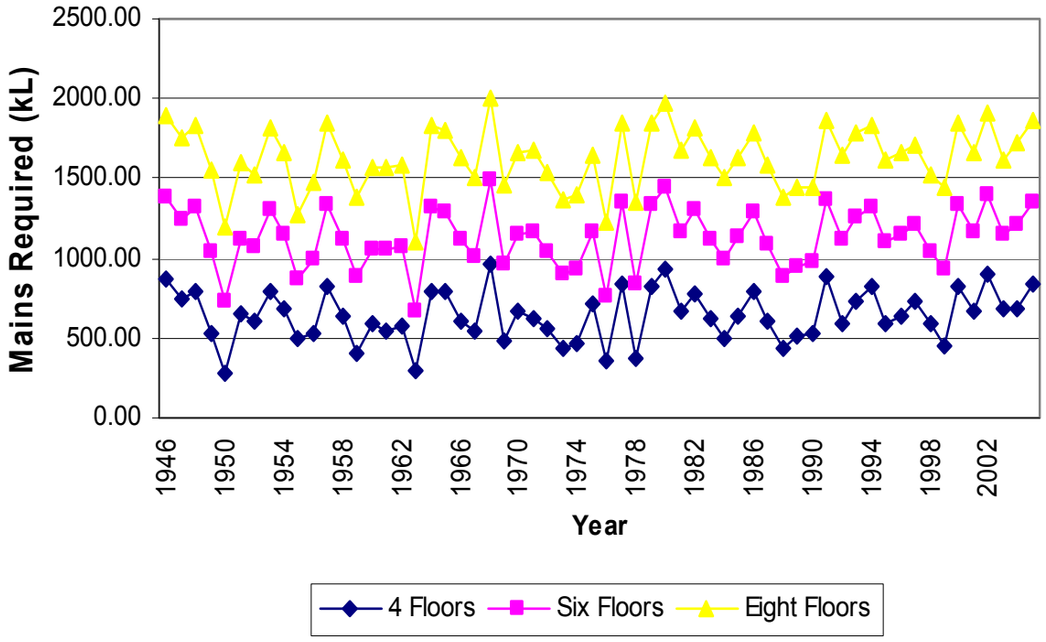


Fig. 16. Mains top-up required vs. water demand (Non-BASIX and 2,000m² site area)

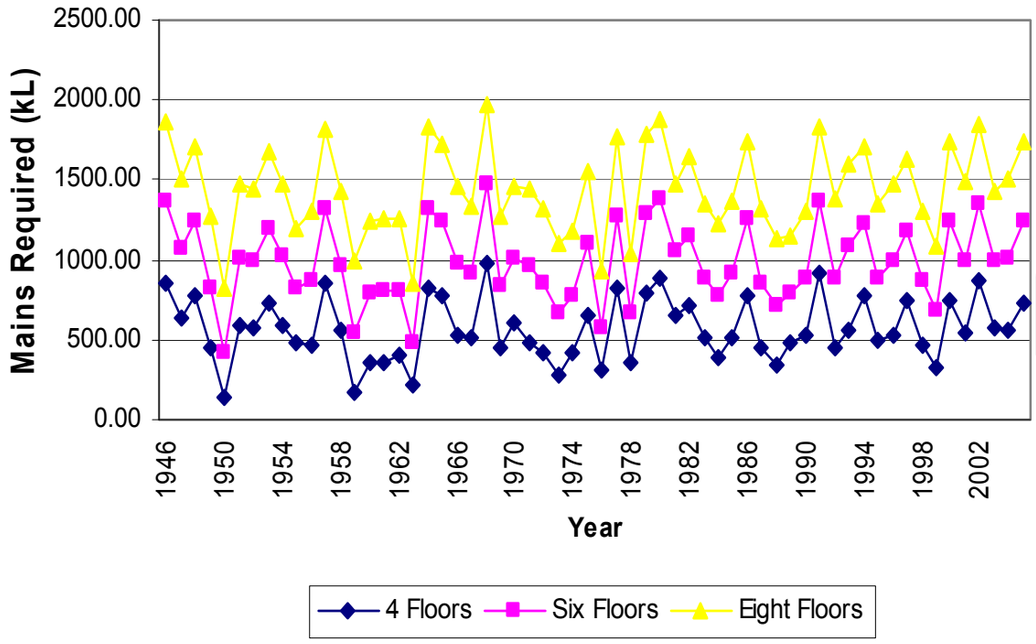


Fig. 17. Mains top-up required vs. water demand (Non-BASIX and 4,000m² site area)

The water saving is the most significant component of a rainwater harvesting system as this eventually determines the viability of the system. A rainwater harvesting system that produces little water savings is unlikely to be financially viable. Figures 18 to 21 compare the average water savings over the sixty year analysis period for a number of scenarios.

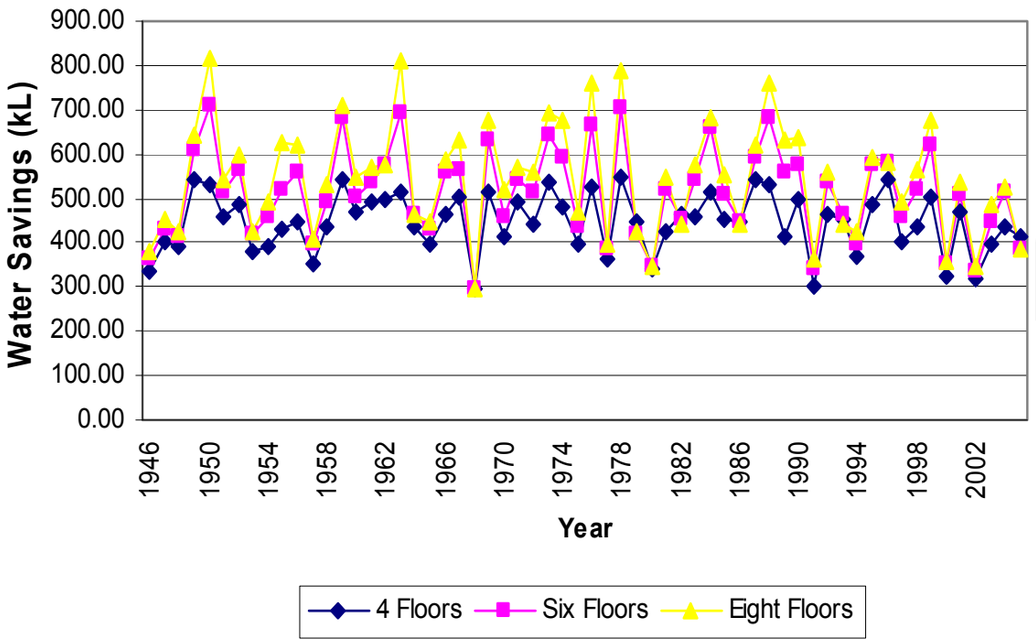


Fig. 18. Water savings (BASIX and 2,000m² site area)

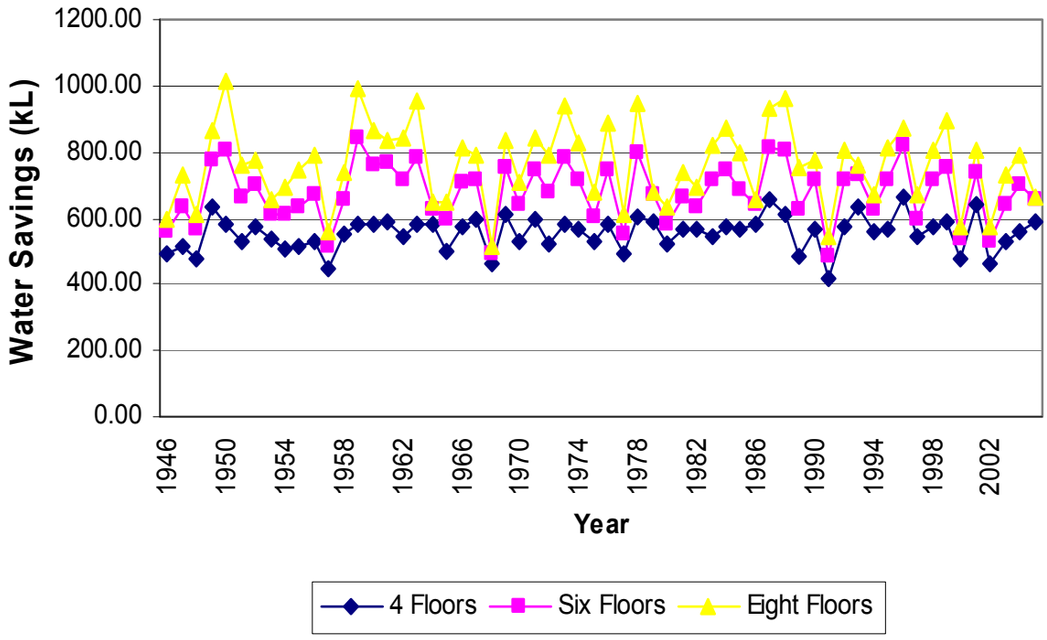


Fig. 19. Water savings (BASIX and 4,000m² site area)

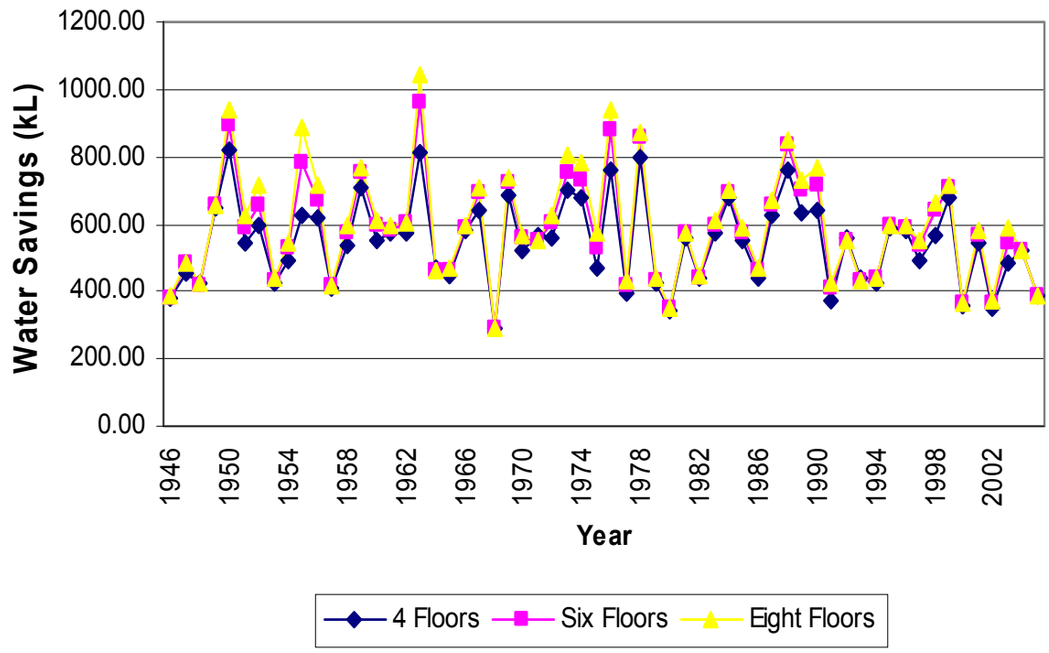


Fig. 20. Water savings (Non-BASIX and 2,000m² site area)

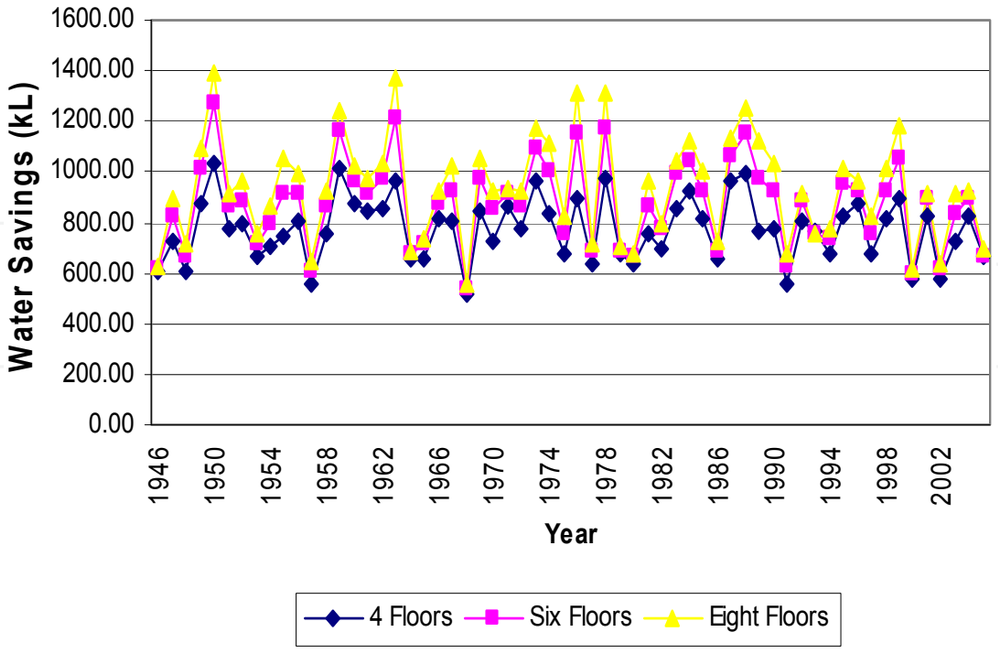


Fig. 21. Water savings (Non-BASIX and 2,000m² site area)

These figures show an increase in water savings in relation to an increasing water demand. The water savings also increase with an increased roof area despite the mains top-up required decreasing for larger roof areas. It can also be seen from these figures that the maximum water savings occur with the non-BASIX approach for an eight-floor scenario with a 4,000m² site area. It is this scenario that is likely to be the most financially viable option although the increased installation costs of the additional floors might offset the additional savings gained.

The following scenarios are considered in the life cycle cost analysis (LCCA). Four different interest rates/discount rates are considered 5%, 7.5%, 10% and 15% per annum. It is also assumed that water price would increase at three different inflation rates: 2.6%, 3.5% and 4.5% per annum. Two different water prices are considered: $1.264/kL and $1.634 per kL. All costs considered here are in Australian dollars.

Scenario 1: BASIX compliant four-floor case built on a site area of 2,000m²
Scenario 2: BASIX compliant six-floor case built on a site area of 2,000m²
Scenario 3: BASIX compliant eight-floor case built on a site area of 2,000m²
Scenario 4: BASIX compliant four-floor case built on a site area of 4,000m²
Scenario 5: BASIX compliant six-floor case built on a site area of 4,000m²
Scenario 6: BASIX compliant eight-floor case built on a site area of 4,000m²
Scenario 7: Non-BASIX compliant four-floor case built on a site area of 2,000m²
Scenario 8: Non-BASIX compliant six-floor case built on a site area of 2,000m²
Scenario 9: Non-BASIX compliant eight-floor case built on a site area of 2,000m²
Scenario 10: Non-BASIX compliant four-floor case built on a site area of 4,000m²
Scenario 11: Non-BASIX compliant six-floor case built on a site area of 4,000m²
Scenario 12: Non-BASIX compliant eight-floor case built on a site area of 4,000m².

The maximum water savings are achieved when water demand is the highest. This occurs for Scenario 12 where the annual water savings achieved is 934kL. The minimum water savings occurs for Scenario 1 which produces an average of 446kL water saving per year. The minimum mains water requirement, however, occurs for Scenario 4 which on average requires 95kL annually and produces yearly water savings of 555kL. Furthermore, the model shows that for some years, mains top-up would not be required at all. It is also found that the performance of the rainwater tank improves significantly with the increasing size of the roof catchment. The larger roof area results in a larger inflow to the rainwater tank providing greater savings, if the harvested water can be utilised.

The capital and operating costs are estimated using the Sydney market price for each of the scenarios mentioned above. The highest capital and operating costs are produced for Scenario 12 as a result of the increased plumbing reticulation costs involved with plumbing the extra floors and additional lengths of down piping required for the larger building area. An increased water demand also results in higher pump operating costs than the other scenarios.

A LCCA is performed on each of the above scenarios to determine the most viable option i.e. the highest benefit/cost ratio. The price of water, the inflation rate of water and the interest rate/discount rate are also considered as variables. The best case benefit/cost ratio is found to occur for Scenario 10 and the worst benefit/cost ratio for Scenario 3. It is found that the financial viability improves at lower interest rates and higher water prices. The best case scenario is therefore found to occur at a water price of $1.634/kL at 4.5% inflation rate for water price and an interest rate of 5%. The benefit/cost ratio produced is 1.39 which results in a payback period of 38 years. It is noted that the rainwater harvesting system is not able to payback at an interest rate of 7.5% and other higher rates for the scenarios considered here. At the current water price, it is only possible to payback if the inflation rate of water is at 4.5% which is likely to happen considering dwindling water supplies in Sydney and recent water price increases. At the higher water rate of $1.634/kL and 4.5% inflation, the BASIX compliant unit is able to payback with the eight-floor scenario being the most viable at a benefit/cost ratio of 1.15 and a payback period of 50 years.

Figure 22 shows the yearly cumulative costs and benefits for the best possible scenario. In the first year, the difference between cost and benefit is $33,904 which indicates that there is a loss of -$33,904. As the years go on, the cumulative benefits increase and the cumulative costs decrease. At year 38, the benefit is equal to the cost when the savings crosses the x-axis. The water price, rate of inflation, and operating cost determine how fast the benefit becomes equal to the cost. It can be seen that the total benefit in 60 years is $20,539 indicating that not only has the rainwater harvesting system is paid back, it has saved the owner $20,539.

It can therefore be concluded, from a financially viable perspective, that it is possible to achieve a payback for a rainwater harvesting system under some favourable conditions. The largest single factor affecting the viability of a rainwater harvesting system is the cost of mains water. The higher the cost of mains water, the more viable the rainwater harvesting system becomes. From an environmental perspective, rainwater harvesting systems have the ability to reduce reliance on mains water leading to lower infrastructure cost and possible deferment of new infrastructure such as dams.

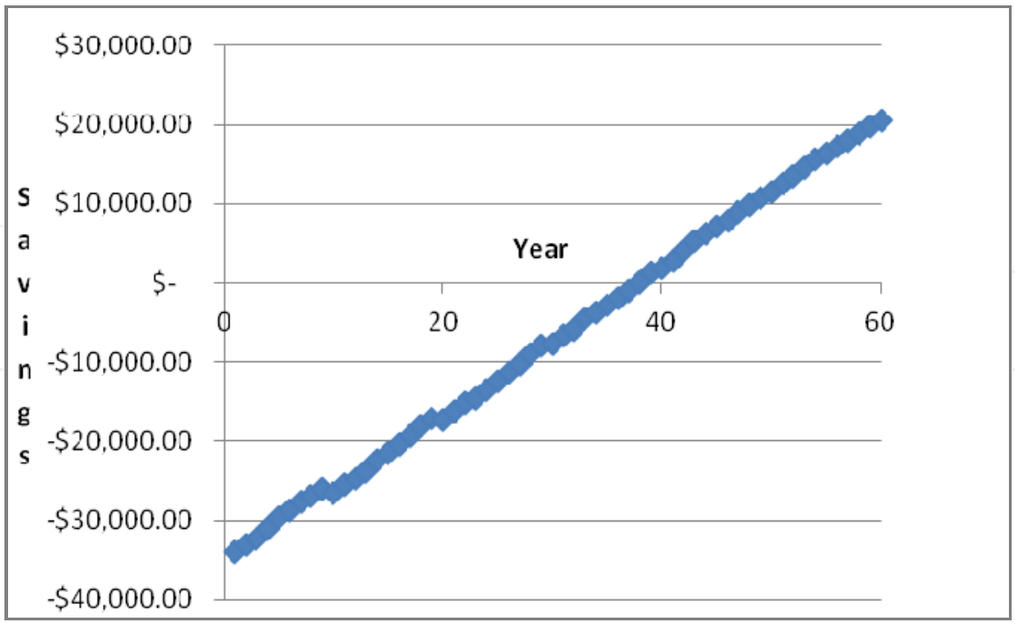


Fig. 22. Annual benefits and costs of the best possible scenario for the rainwater harvesting system

A breakdown of the different cost components of the whole life cycle cost is presented in Table 2. It can be seen that the capital cost comprises the highest component (66%) whereas the maintenance cost is the second highest contributing 18%. The pump operating cost only contributes 6% of the total cost although when added to the pump capital, replacement and maintenance costs the total expenditure of the pump jumps to $9,872 or 19% of the total life cycle cost. This is quite significant and whether or not a rooftop rainwater tank is justified may be a subject to further research as with a rooftop tank there would be no pump cost. Although, the weight of a 75kL rainwater tank is likely to add significant structural cost to the building which may not justify a rooftop rainwater tank.

Cost item	Life cycle cost (Aus$)	% of whole life cycle cost
Capital	$34,575	66
Replacement	$4,151	8
Maintenance	$9,375	18
Pump operating cost	$2,847	6
GST	$1,222	2
Total	$52,173	100

Table 2. Breakdown of whole life cycle cost for the best possible scenario of the rainwater harvesting system

4. Conclusion

This chapter presents a computing tool that can be used to examine the water savings potential and financial viability of a rain water harvesting system in a multi-storey building.

A case study is presented for a 75kL rainwater tank, located in Sydney, Australia. It is found that the performance of a rain water harvesting system in terms of water savings improves significantly with the increasing roof size and water demand. It is also found that for most of the typical scenarios the rain water harvesting system is not financially viable at the current water prices in Australia, which is highly subsidized and in the current high interest regime (greater than 7%). In a few cases however, the rain water harvesting system is likely to be financially viable, in particular at smaller interest rates and higher water prices. It is also found that the capital cost represents the highest component in the whole life cycle cost of a rain water harvesting system followed by the maintenance cost. The outcomes of this study suggests that government authorities should consider increasing the subsidy for a rain water harvesting system to offset the financial burden of the home owners to encourage the installation of rain water harvesting systems. It should be noted that there are significant environmental benefits of a rain water harvesting system such as water conservation and on-site retention of pollutants. Rainwater harvesting system also increases the resilience of the urban water supply system, which is important during drought years, which is common in Australia. Rainwater harvesting system is also likely to defer construction of major water supply dam and desalination plant.

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Cities are growing as never before and nowadays, it is estimated that at least 50% of the world's population lives in urban areas. This trend is expected to continue and simultaneously the problems in urban areas are anticipated to have an increase. Urbanization constitutes a complex process involving problems with social, economic, environmental and spatial dimensions that need appropriate solutions. This book highlights some of these problems and discusses possible solutions in terms of organisation, planning and management. The purpose of the book is to present selected chapters, of great importance for understanding the urban development issues, written by renowned authors in this scientific field. All the chapters have been thoroughly reviewed and they cover some basic aspects concerning urban sustainability, urban sprawl, urban planning, urban environment, housing and land uses. The editor gratefully acknowledges the assistance of Dr Marius Minea in reviewing two chapters.

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