TWO DECADES OF HOUSEHOLD WATER AND ENERGY MONITORING – RAINWATER HARVESTING TO SOLAR BATTERY STORAGE

Peter J Coombes[1]

ABSTRACT: *This paper provides a narrative of insights and experience derived from two decades of monitoring of a sustainable house in the inner city suburb of Carrington in New South Wales. Water efficient appliances, rainwater harvesting, solar panels and battery storage reduced demands for grid water and energy, and provided resources to the grid. Use of rainwater harvesting and edible rain gardens reduced stormwater runoff from the property which has potential impacts to mitigate flooding and improve waterway health. It was a key insight that the house operates as a system with feedback loops rather than the sum of performances from each household appliance, water saving measures and human behaviours. These insights revealed a need to calibrate household behaviours and sustainable systems for optimum performance. The observed annual reduction in household expenditure for utility services was $2,126.*

KEYWORDS: Household, systems, behaviour, efficiency, water, energy, rainwater, solar, grid, economics

[1] Peter J Coombes, Urban Water Cycle Solutions, Newcastle. Email: peter@uwcs.com.au

ISBN: 978-1-925627-03-9

1 INTRODUCTION

A house located at an inner city suburb of Carrington in the city of Newcastle has incrementally installed sustainable measures including rainwater harvesting, water efficient appliances, rain gardens, solar panels and battery storage during the last two decades. The house aims for efficiency and operates by sourcing rainwater and solar energy first with back up from the grid. This sustainable house has been continuously monitored since 1997 and the monitoring includes climate, energy, rainwater and mains water use, stormwater runoff, costs, human behavior and maintenance issues. There were also design changes during the monitoring period including different rainwater bypass and top-up solutions. The sustainable elements created a range of different interactions with approval authorities and institutions. This paper builds on previous publications[1],[2],[3] to provide a narrative of results and insights from two decades of monitoring and experience of operating the house.

Figure 1: *The Carrington house and the rainwater harvesting system (circa 2004)*

2 OVERVIEW

The water and energy components of the Carrington House have evolved over the two decades since 1997. Similarly the lifestyles of the residents and complexity of the monitoring programs have adapted to different configurations of house over time. The timelines of key events and the monitoring processes are discussed in this Section.

2.1 A TIMELINE OF ACTIONS

The Carrington house was purchased and occupied by a family of two people during 1997. A clothes dryer was installed in June 2003 and, during October 2003, a dual water supply system (rainwater harvesting and mains water) and a water efficient clothes washer was installed. The rainwater harvesting system included two 2.2 kL rainwater tanks with back up from mains water supplies via trickle top up to a minimum water level in the rainwater storage. The trickle top arrangement was created to overcome water utility resistance to dual water supplies. The design of the dual water supply system aimed to source rainwater first for all household water uses and utilise mains water when rainwater was not available. Pictures of the property (circa 2004) and the rainwater harvesting system are provided in Figure 1.

An air conditioner and a kitchen garden were added to the property during January of 2004. All overflows from the rainwater tank were directed to the kitchen garden and associated pervious surfaces. This arrangement concerned trades people and council officers because standards require that overflows from rainwater tanks are discharged via pipes to the street gutter. Whilst the design philosophy for the Carrington house was to maximise sustainability, there were human behaviour requirements (clothes dryer and air conditioner) and regulatory obligations or perceptions about institutional rules to overcome. The original configuration of the property and rainwater harvesting system is shown in Figure 2. Note that the dual check values in the three water meters and an air gap in the tank provide multiple barrier protection against an unlikely chance of backflow of rainwater into the mains water. However, a check valve in the water meter at the property boundary provides adequate protection.

The property was occupied by tenants (two single young men) during the period 2008 to 2011. There were short periods where the house was not occupied during 2008 and 2011. The owners returned to the house during 2012 and installed a 5 kL slimline rainwater tank with a submerged pump, a water filter (30 micron filter to remove sediments) at the pump intake and a mains water pressure bypass arrangement.

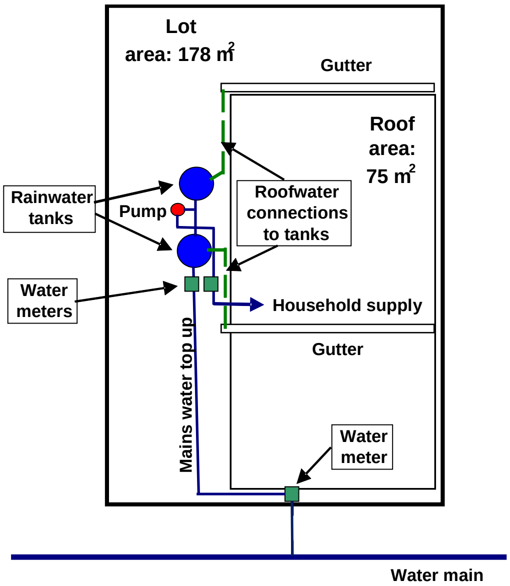

Figure 2: *Configuration of the Carrington house and the rainwater harvesting system (circa 2004)*

In addition, 8 solar panels (1.5 kW capacity) and an inverter (transforms direct current DC energy to alternating current AC energy) was installed. Solar energy was exported via the inverter from the house to the electricity grid. A comprehensive monitoring program identified a leaking toilet cistern and outdoor tap. A new 4.5/3 litre flush toilet and outdoor tap was installed.

Water quality monitoring (microbial, physical and elemental characteristics) at the site revealed acceptable rainwater quality at the household taps.[1] The results of national studies into rainwater quality by Evans et al., (2009)[4] established that the microbial quality of rainwater supplies were often of acceptable quality for supply to the entire house. Results of this study indicated that leaf diverters were highly effective for improving rainwater quality which motivated installation of a leaf diverter. Pictures showing the solar panels and the slimline rainwater tank with downpipes discharging into the tank via a single leaf diverter are provided in Figure 3.

Spinks (2007)[5] and Morrow et al., (2010)[6] confirmed that roofwater quality improves in the incidental rainwater treatment train and elemental quality of rainwater was usually acceptable for whole of house uses.

Figure 3: *Configuration of the Carrington house and the rainwater harvesting system (circa 2012)*

It was also established that household plumbing can be a source of contamination in household systems, regardless of the water source. An under-sink filter (0.1 micron filter and activated carbon) was installed on the drinking water tap to remove any residual microbial and elemental contaminants that might occur.

The property was occupied by a tenant (a single lady) during 2013 and 2014. The owners returned to the house during 2015 and found that difficulties with the pressure bypass arrangement had reduced use of rainwater. This resulted in ponding of overflows from the rainwater tank in the garden and motivated a plumber to pipe the rainwater overflows to the street. The issues with the mains water bypass system were subsequently overcome. Nevertheless, our monitoring revealed that pressure bypass arrangements source mains water first regardless of the availability of rainwater.

The house was renovated during February and March of 2017. A 7.5 kW solar battery (purchased from BYD) and 8 additional solar panels (2 kW capacity) with micro-inverters (purchased from Enphase) were installed. The solar storage system was designed as primary energy supply to the house with back up from the electricity grid and export of excess solar energy to the grid. After considerable discussions with the supplier, the solar energy system was also configured to operate during periods when the electricity grid was not operating (outages). Micro-inverters were chosen to maximise generation of solar energy during periods of partial shade from surrounding buildings. Solar arrays with a single centralised inverter usually cease generating energy in partial shade situations.

The submerged pump and pressure bypass system was replaced with a variable speed external epump (sourced from Claytech) and hydraulic bypass arrangement (sourced from Beltrami). This process aimed to source rainwater first, eliminate standby energy for the bypass arrangement and ensure the rainwater pump only used an optimum amount of energy. This arrangement was a departure from traditional pumps that have fixed energy profiles and mains water bypass arrangements that require standby energy. The old galvanised iron pipes in household plumbing network were also replaced. The battery storage, epump and hydraulic mains water bypass device are shown in Figure 4.

Figure 4: *The battery storage near the tank, epump and hydraulic bypass device (circa 2017)*

2.2 MONITORING PROGRAM

The monitoring program evolved over time in response to the additional sustainable elements in the house. Monitoring commenced in 1997 with examination of utility bills for water and electricity uses. Daily manual readings of water and energy meters were added to the monitoring regime during 2000. During 2002, the smart water meters (measurements at one minute intervals) were installed at the mains water connection from the street mains, and at the rainwater supply and, mains water bypass to the house. This monitoring was augmented with diary studies of water and energy use behaviours. A local weather station was also included in the monitoring to measure rainfall, temperature, wind speed and direction at one minute intervals. Water levels in the rainwater tanks were also continuously observed using a pressure sensor.

During 2017, energy smart meters were installed to monitoring electricity demand in 8 different household circuits. These measurements were augmented by recordings (at 5 minute intervals) of the energy balance at the BYD battery storage (solar energy in, grid energy in, battery storage, household energy supply and export of solar energy to the grid). The generation of solar energy from the solar panels was also recorded, at five minute intervals, using the Enphase system.

3 RESULTS

The behaviour of the Carrington house as defined by monitoring method and during periods of intense monitoring are summarised in this Section.

3.1 UTILITY BILLS

The use of mains water was collated from Hunter Water bills during the period 1997 to 2017 and is presented in Figure 5.

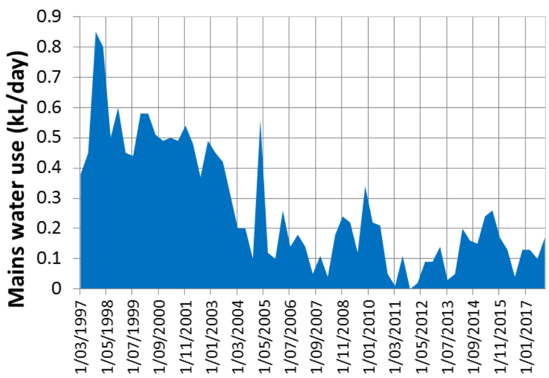

Figure 5: *Mains water use for the period 1997 to 2017 from Hunter Water bills*

Figure 5 shows the dramatic reduction in demand for mains water after installation of the rainwater harvesting system in 2003 and the water efficient appliances in 2004. Variation in mains water demand after 2003 was driven by rainfall, changes in behaviour of residents and further additions to the household water system. The average mains water use was 0.52 kL/day prior to 2003 and was 0.14 kL/day after 2012. This represents a 74% annual reduction in mains water use for and annual average saving of 139 kL and a cumulative saving of 2,820 kL since 2003.

The use of grid electricity (Grid In) and export of solar energy to the grid (Solar Out) was collated from Energy Australia bills during the period 1999 to 2017 and is presented in Figure 6.

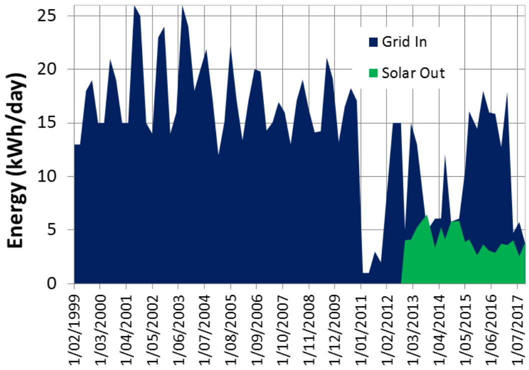

Figure 6: *Energy imported from the Grid and solar energy exports to the Grid for the period 1997 to 2017 from Energy Australia bills*

Figure 2 reveals increasing reductions in energy use after 2003. Average daily use of grid energy was 18.5 kWh prior to 2003 and 4.7 kWh during 2017. This represents a 74% reduction in annual demand for grid energy (5037 kWh). In addition, the average daily export of solar energy to the grid was 4.1 kWh after 2012. The use of grid energy decreased by 8% to 17 kWh/day during the period 2003 to 2012 following installation of the rainwater harvesting system, air conditioner, clothes dryer and water efficient clothes washer. Note that periods of low energy use due to absence of residents was excluded from this calculation.

This result was different to the conventional assumption that installation of rainwater harvesting systems increase household energy use. The reduction in household use of grid energy is significant given that an air conditioner and clothes dryer was operating during that period. So the reduction in energy use was greater than 8% in response to installation of the rainwater harvesting system which indicates that the house operates as a system rather than the sum of behaviours from individual appliances and fixtures. Subsequent detailed monitoring demonstrated that the interaction of lower flowrates from the rainwater pump with household appliances created an overall reduction in the household energy profile.

Installation of the solar panels (1.5 kW array) in 2012 resulted in a further reduction in average daily grid energy use to 12 kWh (29%) from 2012 use. In 2017, the addition of a 2 kW array of solar panels and battery storage that changed the primary energy source of the house to solar (with back up from the grid) reduced daily average use of grid energy to 4.7 kWh. However, the household's daily use of grid energy is higher than actual equilibrium use due to periods of partial performance whilst calibrating the software operating solar battery storage system and household behaviours. For example, optimum use of solar energy was obtained by shifting high energy uses from evenings to daytime when sunshine was available.

3.2 DETAILED OBSERVATIONS FROM 2003 TO 2004

Installation of the rainwater harvesting system motivated the range of detailed monitoring programs outlined in Section 2.2. A diary study of household uses was operated over a period of 9 months (July 2003 to April 2004) and included documentation of the time of all water uses – for example, a single flush of the toilet at 2 pm. This information was combined with continuous sequences of water use from 3 smart water meters (see Figure 2) to produce the distribution of household water use shown in Figure 7 and sequences of rain and mains water use presented in Figure 8.

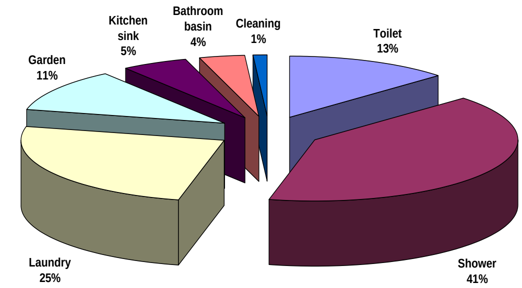

Figure 7: *Distribution of household water use*

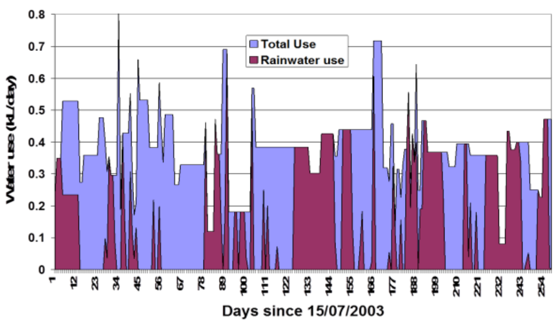

Figure 8: *Sequence of daily household mains and rain water use from July 2003 to April 2004.*

Figure 7 shows that household water use at the Carrington house is dominated by showers, laundry and toilet uses (79% of water use). Figure 8 shows

significant periods of rainwater supply during a period of low rainfall. Average daily rainfall was 2.38 mm/day (40% below average). The household water balance during the intense monitoring period was 0.21 kL/day for mains water, 0.16 kL/day for rainwater and 0.15 kL/day for water efficiency. This represented a 60% reduction in mains water use.

Household use of grid energy was 17.1 kWh/day during the selected monitoring period which is a 7% reduction in use. Detailed analysis revealed that the interaction between the lower flowrate of the rainwater pump, and water efficient clothes washer and low flow shower reduced heating energy use. The interface between lower flows from the rainwater pump and a water efficient clothes washer that operates under low flow conditions that also pumps and heats water (this was a surprise) reduced energy use. Energy use of the rainwater pump was also minimised by fully opening the valve on the plumbing to the toilet cistern which avoided energy intensive pump cycling.

3.3 DETAILED OBSERVATIONS FROM 2015 TO 2017

The household water and energy systems were upgraded during 2012 to include a 5 kL slimline rainwater tank with a submerged pump and a pressure driven mains water bypass system (see Section 2.1 for further details). Daily sequences of mains and rainwater use during the period October 2015 to January 2017 are shown in Figure 9.

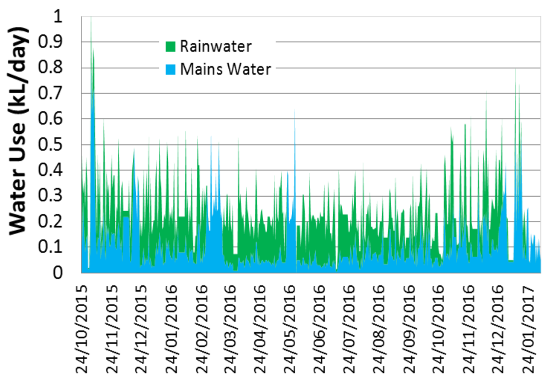

Figure 9: *Sequence of daily household mains and rain water use from October 2015 to January 2017.*

Figure 9 reveals significant periods of rainwater use throughout the detailed monitoring period. The average daily household water balance was 0.11 kL/day for mains water, 0.14 kL/day for rainwater and 0.27 kL/day of water efficiency. This was a 79% reduction in mains water use. The higher level of water efficiency was generated by discovery and fixing of water leaks at an outdoor tap and in the toilet cistern. The smart metering facilitated the elimination of leaks in the household water system and also revealed that mains water was always chosen first in the dual water supply system that was reliant on the pressure bypass arrangement. The mains bypass arrangement only selected rainwater after 2 litres of water use and if water flowrates were greater than 2 litres per minute. So toilet flushing, the clothes washer and taps with mostly low volume or low flowrate used a high proportion of mains water regardless of availability of rainwater. This explained the reduced rainwater use during this period of higher rainfall (average daily rainfall: 2.94 kL/day).

Daily use of grid electricity (Grid In) and solar energy (Solar), and export of solar energy to the grid (Solar Out) during the period October 2015 to January 2017 is presented in Figure 10.

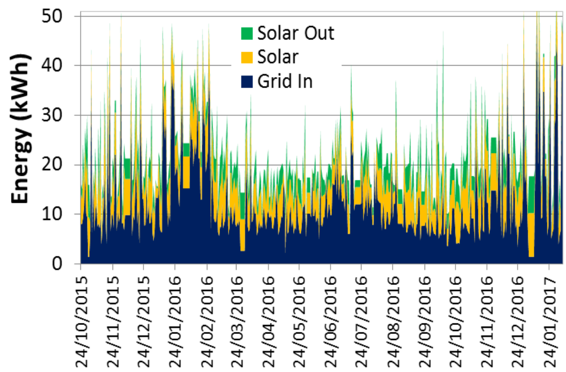

Figure 10: *Sequence of daily household use of grid and solar energy and export of solar energy to the grid from October 2015 to January 2017.*

Figure 10 shows that use of electricity from the grid was higher in Summer due to use of the air conditioner and in the Winter in response to use of the clothes dryer. A significant proportion of household energy use was provided by solar energy and there was consistent export of solar energy to the grid. Installation of the solar panels has reduced average daily use of grid electricity to 11.88 kWh (a 35% reduction), average daily use of solar energy was 6.15 kWh and average daily export of solar energy to the grid was 3.17 kWh.

Monitoring data was combined with the characteristics of the property in the Systems Framework[7] to simulate (6 minute time steps) the performance of the property without rainwater harvesting and rain gardens. Observed daily rainfall, rainwater storage volumes, stormwater runoff from the property and simulated stormwater runoff from the property without the WSUD measures (BAU runoff) is shown in Figure 11.

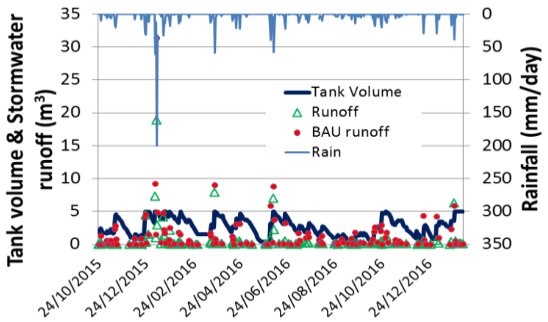

Figure 11: *Daily rainwater storage, rainfall and stormwater runoff from October 2015 to January 2017 as compared to BAU stormwater runoff*

Figure 11 shows that the volume of rainwater storage varies with rainfall as expected. The volume of rainwater storage is regularly reduced which corresponded to consistent reductions in stormwater runoff (average reduction 55%) in comparison simulated runoff form the property without WSUD measures. This effect is highlighted by the position of BAU runoff (as shown by the blue dots) to actual site runoff designated by the red line in Figure 12.

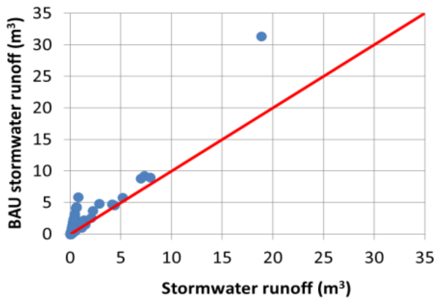

Figure 12: *Comparison between simulated BAU runoff (blue dots) and actual runoff (red line)*

Figure 12 demonstrates that simulated BAU runoff denoted by blue dots is often greater than the red line which is actual runoff from the property. If the rainwater harvesting and rain gardens did not reduce runoff all blue dots would be located on the red line. It is also shown that the property provided substantial stormwater storage of over 12 m^2 during a 200 mm rain event (43% reduction in runoff volume). The reductions in stormwater runoff are partially provided by the available storage in the rainwater tank prior to rain events as shown in Figure 13.

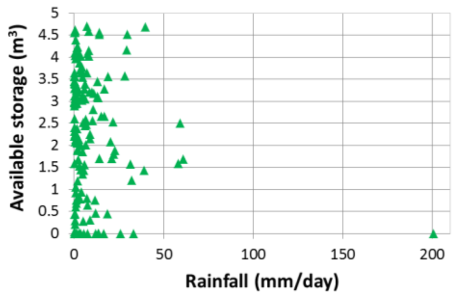

Figure 13: *Observations of available storage in the rainwater tank prior to rain events*

Figure 13 demonstrates that there was available storage in the rainwater tank prior to the majority of rain events. Note that the 200 mm daily rainfall in Figure 13 was the second day of a larger rain event. The probability of available storage in the tank prior to rainfall was 90% and the average rainwater storage available prior to rain events was 2.3 m^3. The available storage in the tank during monitoring period was estimated as:

$$Available\ storage\ (m^3) = 2.3 - 0.31 rain(mm)$$

3.4 DETAILED OBSERVATIONS IN 2017

Detailed monitoring of the Carrington house continued in April 2017 (see Section 2.2) after a substantial renovation of the house (see Section 2.1). Observed daily mains and rain water use is shown in Figure 14.

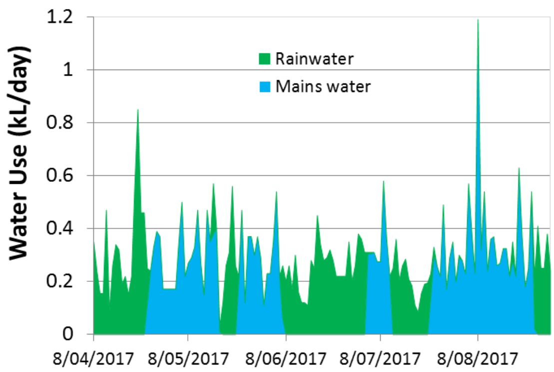

Figure 14: *Sequences of daily household mains and rain water use from April 2017*

Figure 14 shows that the house was either supplied by rainwater or mains, and there were significant periods of rainwater supply. The hydraulic bypass arrangement has ensured that rainwater is supplied to the house when rainwater is available in the tank.

ISBN: 978-1-925627-03-9

The average daily household water balance was 0.17 kL/day for mains water, 0.12 kL/day for rainwater and 0.23 kL/day of water efficiency. This was a 67% reduction in mains water use. The yield from rainwater harvesting was diminished due to the lower rainfall during this period (average daily rain: 2.35 mm/day).

The household energy system was upgraded to include additional solar panels and battery storage. Operation of the household energy systems also utilised solar energy before seeking backup supply from the grid. Daily use of grid electricity (Grid In) and solar energy (Solar), and export of solar energy to the grid (Solar Out) after April 2017 is presented in Figure 15.

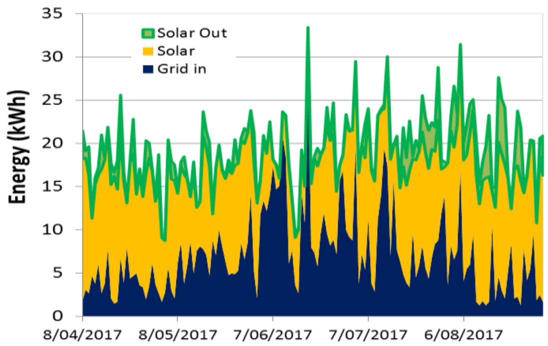

Figure 15: *Sequence of daily household use of grid (Grid In) and solar energy (Solar) and export of solar energy (Solar Out) to the grid from April 2017.*

Figure 15 shows that the additional solar panels and battery storage has dramatically reduced household use of grid electricity and decreased export of solar energy to the grid. Average daily use of energy from the grid was reduced to 7.2 kWh (61% reduction). Average daily use and export of solar energy was 10.7 kWh and 1.5 kWh. However these results are distorted by the impact of the calibration of the battery storage, and institutional and household behaviours that increased use of grid energy as shown in the middle section of Figure 15. The latter portion of the graph represents the equilibrium energy balance for the household.

The calibration of the battery storage and solar energy system required changes to the software operating the system to account for household energy system and a requirement that the solar energy system continued to supply the house during outages of grid electricity supply. There was a need to alter the default position of sourcing grid energy first and automatic shut-down of the energy system when grid energy was not available. The order of operation of the household energy system is now established to source solar energy first, then energy from the battery storage and finally energy from the grid. Wherever possible, additional energy supply from the grid is sourced during off-peak periods which shifts the household grid energy peak and reduces costs.

Discussions with the energy utility about changing operation of our storage hot water service to off-peak heating revealed a change in definition of off-peak hot water rates. The energy utility insisted that the hot water service was already operating at an off-peak rate but this understanding only referred to a reduced tariff (off-peak hot water) that was not a change in the timing of the operation of the hot water system to off-peak periods. A change to off-peak operation of the storage hot water service halted the continual reheating of water and dramatically reduced energy use in the latter portion of the monitoring period. The planned next addition to the household system is solar hot water but a similar issue remains with requiring that the solar hot water system does not continually reheat using grid energy. An example of the human calibration of the energy system is provided in Figure 16.

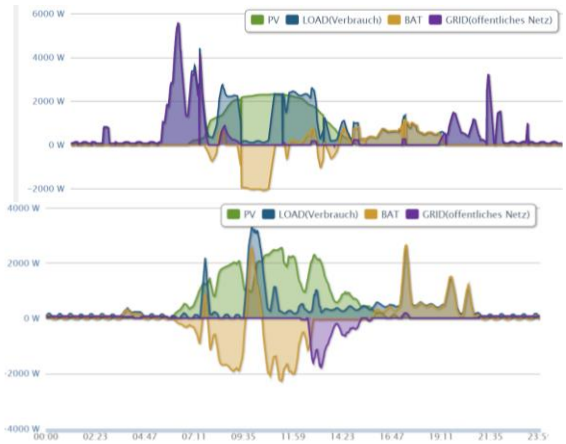

Figure 16: *Human calibration of the energy system: the top pane shows high energy use early in morning and the bottom pane shows high use during the day (purple is grid energy, blue is energy consumption, green is solar power generation and brown is use of battery storage energy)*

Figure 16 (top pane) shows use of higher energy using appliances (clothes washer, clothes dryer and vacuum cleaner) early in the morning which reduced battery storage and increased grid energy use in the morning and evening. Using the appliances later in the day (bottom pane) almost eliminates grid energy use and removes the early

and morning energy peak. The human calibration process contributed to substantial reductions in grid energy use during the latter portion of Figure 15. Observed daily rainfall, rainwater storage volumes, stormwater runoff and simulated stormwater runoff from the property without the WSUD measures (BAU runoff) are shown in Figure 17.

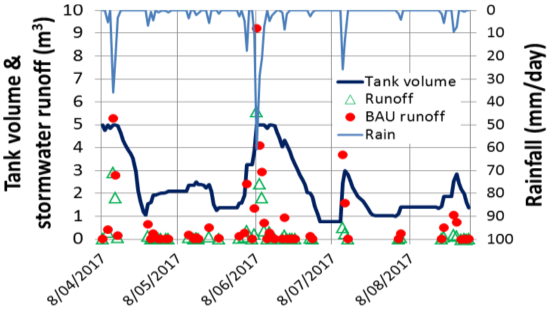

Figure 17: *Daily rainwater storage, rainfall and stormwater runoff after April 2017 as compared to BAU stormwater runoff*

Figure 17 demonstrates that stormwater runoff from the property with rainwater harvesting and rain gardens (green triangles) is consistently less than BAU stormwater runoff (red dots) during the monitoring period. The reductions in stormwater runoff created by rainwater harvesting and site storage, and available storage in the rainwater tank prior to rain events are shown in Figures 18 and 19.

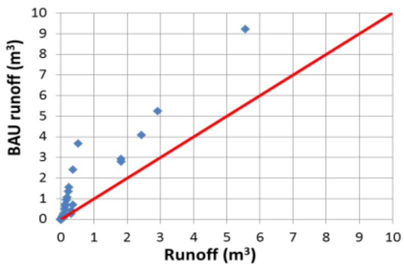

Figure 18: *Comparison between simulated BAU runoff (blue dots) and actual runoff (red line)*

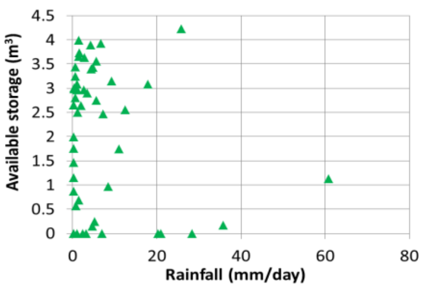

Figure 19: *Observations of available storage in the rainwater tank prior to rain events*

Figure 18 reveals that rainwater harvesting and rain gardens generated consistent reductions in stormwater runoff. Figure 19 demonstrated that storage was available in the rainwater tank prior to most rain events. The probability of available storage in the tank was 82% and the average volume of the storage was 2.05 m^3. The available storage in the tank during the monitoring period was estimated as:

$$Available\ storage\ (m^3) = 2.25 - 0.34 rain(mm)$$

3.5 WATER ENERGY NEXUS?

This investigation revealed that rainwater harvesting using traditional fixed energy profile pumps did not increase household energy use. The additional of a variable speed pump with a hydraulic bypass arrangement was expected to produce a lower energy profile of rainwater supply. Relationships between energy use and rainwater supply was extracted from observations for three water use events:

- Toilet half flush with hand washing (Figure 20)
- Toilet full flush with hand washing (Figure 21)
- Shower use (Figure 22)

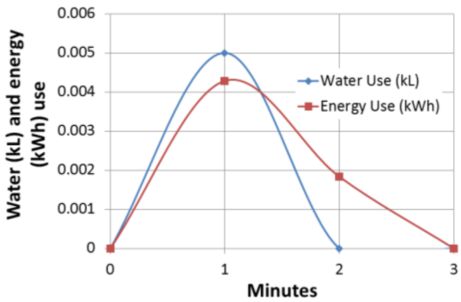

Figure 20: *energy and water use profile for toilet half flush and hand washing*

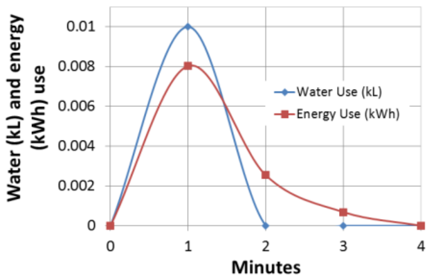

Figure 21: *energy and water use profile for toilet full flush and hand washing*

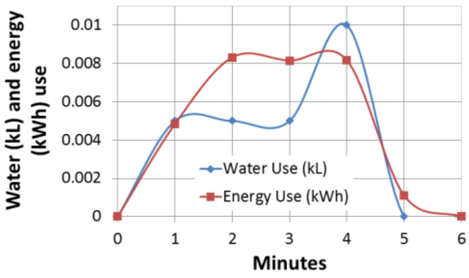

Figure 21: *energy and water use profile for a shower*

Figures 19, 20 and 21 demonstrate that the energy and rainwater use profiles had similar shapes. The variable speed pump matches energy use to rainwater flowrate. A toilet half flush and hand washing required 0.006 kWh of energy which equates to 1.2 kWh/kL of supply. The toilet full flush and hand washing required 0.011 kWh of energy (1.1 kWh/kL) and a five minute shower required 0.03 kWh of energy (1.2 kWh/kL). Analysis of the energy use of the rainwater supply across the entire monitoring period revealed an average energy use of 0.72 kWh/kL. This result highlights that the energy use of rainwater supplies cannot be generalised and multiplied by total rainwater supply. The rainwater supply/energy profile is variable.

4 DISCUSSION

Detailed monitoring and experience over two decades has produced a rich dataset about the Carrington House. Some of this information is summarised in this paper. Installation of water efficient appliances, rainwater harvesting, solar panels and battery storage has resulted in substantial reductions in use of grid water and energy. In addition, the house has significantly reduced stormwater runoff to the street gutter which will reduce urban flooding and impacts on waterway health.

This study highlighted that a house operates as a system with feedback loops rather than as the sum of isolated performances from appliances and local supply solutions. For example, rainwater harvesting resulted in reduced household energy use due to interaction with other appliances and behaviours. These insights reveal a need to calibrate household behaviours and sustainable systems for optimum performance. The sustainable measures reduced household expenditure by $2,126/annum by reducing water ($321) and energy ($1,618) bills, and earning payments for solar energy ($187) exported to the grid. These results demonstrate that small inner city properties can make significant contributions to widespread sustainable outcomes.

5 CONCLUSIONS

This paper provides a narrative of insights and experience from two decades of monitoring. Water efficient appliances, rainwater harvesting, solar panels and battery storage reduced demands for grid water and energy, and provided resources to the grid. Use of rainwater harvesting and edible rain gardens reduced stormwater runoff and potential impacts on flooding and waterway health. It was a key insight that the house operates as a system and average annual reductions in household expenditure for utility services was $2,126.

6 REFERENCES

[1] Coombes P.J., Spinks A., Evans C., Dunstan H., Performance of rainwater tanks at an inner city house in Carrington NSW during drought. *WSUD2004*, Adelaide, 2004

[2] Coombes P.J., Kuczera G., Kalma J.D., Economic, water quality and quantity impacts from use of a rainwater tank in the inner city. *Australian Journal of Water Resources.* 7(2), 2003.

[3] Coombes P. J., Smit M., Byrne J., and Walsh C., Stormwater, waterway and water resources benefits of water conservation measures for Australian cities. *HWRS 2016*, Engineers Australia, Queenstown, New Zealand. 2016

[4] Evans C. A., Coombes P. J., Dunstan R. H., Harrison T. L., Extensive bacterial diversity indicates the potential operation of a dynamic micro-ecology within domestic rainwater storage systems, *Science of the Total Environment*, 407: 5206-5215. 2009.

[5] Spinks A. T., Water quality, incidental treatment train mechanisms and health risks associated with urban rainwater harvesting systems in Australia. *PhD Thesis. University of Newcastle.* Australia. 2007.

[6] Morrow A., Dunstan H., Coombes P. J., Elemental composition at different points of the rainwater harvesting system. *Science of the Total Environment;* 408(20): 4542-4548. 2010.

[7] Coombes P.J., and Barry M.E., A Systems Framework of Big Data for Analysis of Policy and Strategy. *WSUD2015 Conference*. Engineers Australia. Sydney. Australia. 2015

ISBN: 978-1-925627-03-9