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Water sustainable house: water auditing of 3 case studies in Perth, Western Australia

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Abstract

Householders in cities face water-related issues due to the increasing cost and restrictions in water use, especially during drought. They respond in many different ways, ranging from installing water efficient appliances, adopting water-saving behavior and implementing greywater reuse, to being water self reliant (off-mains supply). The latter approach should consider using only rainwater falling on the property boundaries, and if self-supply is from groundwater it should be derived from rainwater falling on the property. Therefore, sustainability depends on the annual rainfall, size of property and availability of storage for water to be used during periods without rainfall. In principle any house can be retrofitted to rely solely on rainwater, because technologies exist to treat subsequent wastewater to any quality desired for reuse. However, the energy requirement and investment needed may negate overall sustainability. Very few studies have assessed water use in households to determine whether relying solely on rainwater is practical or sustainable in the long-term. Three case studies in Perth, Western Australia are reported here, where water auditing has been used for sustainability assessment.

Key words: greywater, groundwater, rainwater, sustainable house, water auditing

INTRODUCTION

Householders in cities face water-related issues due to increasing costs and restrictions in water use during drought. In Perth, Western Australia (WA), for example, water supplied through the mains can only be used to irrigate the garden twice a week, and, more recently, garden irrigation has been banned completely in winter (June to August). Though restriction was introduced during droughts, the measure was retained as a means of controlling water use outside the house.

The water utility in Perth has focused on garden watering restrictions for sustainability, while ensuring water supply availability in the face of continuing decreasing rainfall, since the early 1970s, and increasing population, especially with the recent growth in mining activities in the state. The water utility's approach averted a crisis facing Cape Town, South Africa, in 2018.

The response by householders has ranged from changing to more efficient water appliances (washing machines, dishwashers, dual-flush toilets, high-pressure low-flow shower heads, etc), and adopting water-saving behavior (shorter shower times, operating washing machines and dishwashers only with full loads) to using greywater for garden irrigation.

Sustainability from the householder's point of view reflects the range of responses described above, but could include the desire to be water self-reliant, either fully off-mains or minimizing mains dependence. Being fully off-mains relies completely on rainwater falling within the property boundaries. Sustainability therefore depends on the annual rainfall, size of property and availability of storage

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for water to be used during periods without rainfall. If a private groundwater supply is used, it must be derived from rainwater falling on the property. Vale & Vale (1975) provided information on the self-supply of household water in the United Kingdom. Mobbs (2010) demonstrated that it was feasible to rely completely on rainwater in central Sydney (Australia).

In principle a house can be built or retrofitted to rely solely on rainwater, because technologies are available to treat wastewater to the quality for any desired reuse to supplement rainwater. However, the energy requirement and the investment needed may negate overall sustainability.

Very few studies have assessed household water use to determine whether relying solely on rainwater is practical or sustainable in the long-term. In this paper three case studies in Perth, WA, are reported where rainwater harvesting was practiced and water auditing has been used for water sustainability assessment.

MATERIALS AND METHODS

Water auditing is used to determine the water inputs and outputs of any system over a period, and provides the information needed to assess water use sustainability (Sturman *et al.* 2004). For a household this can mean measuring or estimating water input sources (mains water, rainwater, groundwater) and outputs (wastewater, garden irrigation water, stormwater run-off) and ensuring that there is closure (water balance, outputs = inputs) to within an acceptable limit (say 10%). Any recycling or reuse (e.g. greywater for garden irrigation) is also considered. Water auditing is facilitated using a diagram of water inputs, uses, recycling or reuse, and water outputs, with arrows to indicate flow (volume/unit time) and direction. A boundary is drawn around the system to determine closure.

Water-auditing enables evaluation of where water-related savings can be achieved and maximized, with the lowest investment and operating costs. The technique was applied in three case studies (CS1 to CS3) in Perth, WA.

Perth has a Mediterranean climate. Rainfall in Perth in 2015 (during CS3) as well as average rainfall between 1994 and 2010 are shown in Figure 1. The lack of rainfall in the summer months (December to February) poses a challenge to householders to maintain gardens during this period.

Perth is on the Swan Coastal Plain. It has coarse sandy soils and therefore a shallow, unconfined aquifer. The depth to the water table ranges from 0 (lakes and wetlands as surface expressions) to several meters depending on the topography but at very high ground levels can be greater than 25 m. It is widely drawn on by householders in Perth for irrigating gardens.

While the three houses studied were involved in a broader range of sustainability assessment, including energy efficiency, gardening, waste and wellbeing (Byrne 2016), this paper focuses on water sustainability.

CS1 is a two-bedroom, one-bathroom, semi-detached house on a 330 m^2 block in South Fremantle, Perth. The house was built in 1906 but underwent major renovation around 2003/4, including the installation of water-efficient plumbing. Originally, the property was serviced solely by mains water and sewerage for all demands.

A greywater diversion device – a proprietary system *GRS Water Save* by Greywater Reuse Systems – at the property consisted of two concrete tanks, the first for collection and settlement, and the second a pump chamber. The tanks were sized to hold greywater for up to 24 hours. As new greywater flowed into the collection tank, the retained greywater flowed into the second, activating a submersible pump via a level switch once the set point was reached. The pressurized water was pushed through a coarse filter before use in designated garden areas via dripline irrigation. If the pump failed or the filter blocked, greywater overflow was directed to sewer.

Rain was harvested off 200 m^2 of roof catchment (the entire house roof) via typical roof guttering and 'dry-feed' gravity-drained pipework, where the pipes direct water to the tank and drain empty

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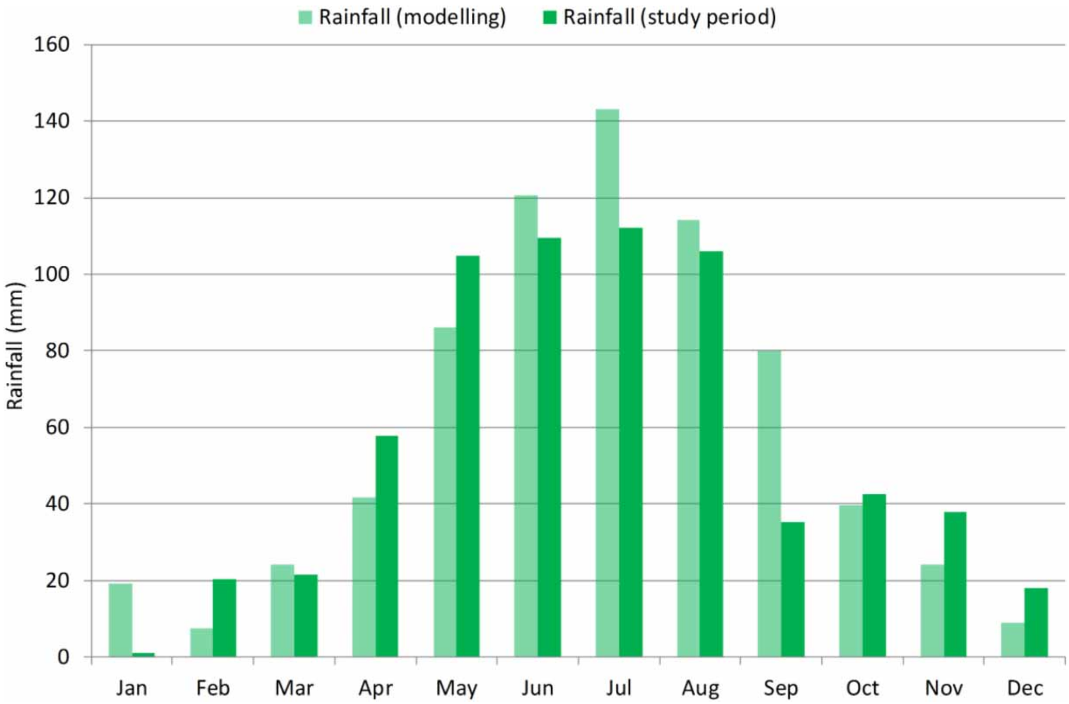

Figure 1 | Comparison of rainfall during the study period (2015) and the recent long-term average (1994–2010) at CS3 (*source:* authors, using data from Australian Bureau of Meteorology Station 009215).

after each rainfall event. All gutter downpipes had leaf traps and first-flush devices with manual drain valves to prevent debris entering the tank.

Rainwater was stored in a 3,500 L buried polyethylene tank with the overflow diverted to a soak-well, which is a hole dug in the soil and lined with bricks or plastic liner without a base to allow water to percolate through the soil. The tank was fitted with a float switch–activated submersible pump, which supplied pressurized rainwater to end-use appliances, etc – toilet, washing machine, irrigation system and garden taps – via a mains water back-up valve. The latter directed rainwater preferentially on demand, when available, and supplied mains water as back-up. Figure 2 shows the water systems for all three case studies.

Six 20 mm Elster V100 cold-water meters were fitted to determine greywater volumes produced and rainwater yield, with sub-metering of toilet, washing machine, irrigation, greywater top-up and garden tap volumes. A Mercoid Series SBLT2 submersible level sensor was installed in the rainwater tank to record tank volumes, to enable comparison of periods of availability with demands. APCS WHT290 Watt-hour transducers were installed on the greywater and rainwater pump power supplies, for daily time-step power use sampling.

CS1 was monitored between 1 July 2010 and 30 June 2011, to assess the contribution of rainwater and greywater reuse in meeting indoor and outdoor water demand. The monitoring was intended to capture water use in a three-person household over a year. Several issues arose during the trial, however, which affected the data, most notably variation of household occupation rates, which was compounded by monitoring equipment malfunctions. The data presented here are therefore based on periods when the equipment was working reliably.

The second property, CS2, is a three-bedroom, one-bathroom, detached dwelling on a 600 m^2 block in White Gum Valley, Perth. The house was built in the mid-1960s but underwent basic renovations around 2009/10, including the installation of water-efficient plumbing fixtures. Originally, the property was serviced solely by mains- water and sewerage for all internal and external requirements.

The proprietary greywater reuse system – a *GreyFlow PS-PP* diversion device by Advanced Wastewater Systems – collected greywater via two interceptor traps containing porous spun polyethylene

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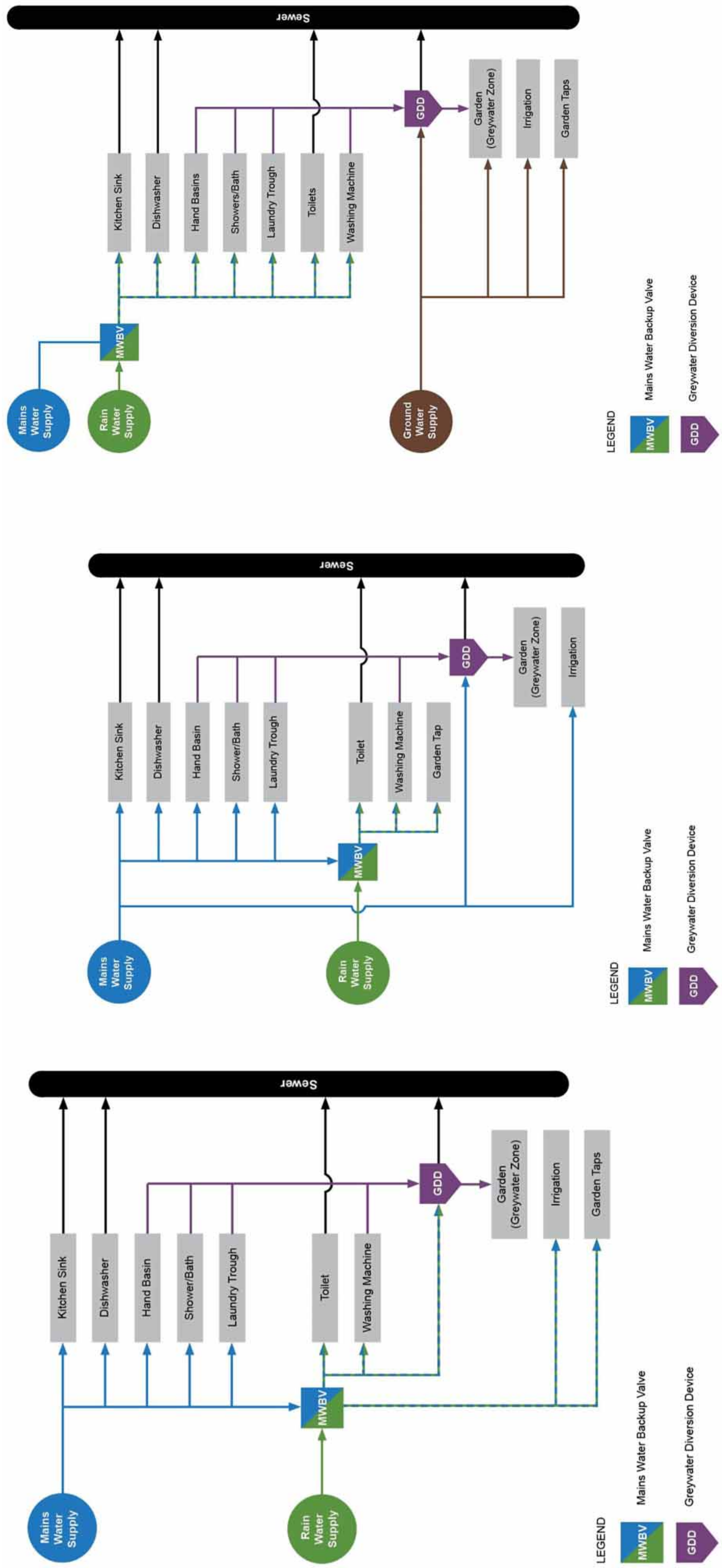

Figure 2 | Water systems for (left to right) CS1, CS2 and CS3.

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pads to provide coarse filtration, prior to filling a 30 L sump housing a submersible pump operated by a level switch. When the trigger level was reached, greywater was discharged to designated garden areas via dripline irrigation. In the event of pump failure or filter blockage, greywater was sent direct to sewer. The device also included an automated filter backflush system. At nominated pump cycles, air was blown through the filter pads to dislodge clogging material. The pump stopped while the blower operated, so that greywater flowing across the filter pads dislodged material from them and took it to sewer.

Rain was collected from a 70 m^2 roof catchment via a standard roof guttering and 'dry-feed' gravity drained pipework arrangement. The catchment area was limited by practical, roof plumbing considerations. There were leaf traps on all gutter outlets to prevent debris entering the tank and a first flush device with manual drain valve was installed prior to the tank.

Rainwater was stored in a 2,500 L above-ground, corrugated steel tank, with the overflow diverted to a soakwell. A pressure-switch activated pump was connected to the tank, and pressurized rainwater supplied on demand (when available) to end-use fixtures – toilet, washing machine, garden tap, etc – via a mains-water back-up valve. Mains-water was supplied as back-up.

CS2′s mains water meter was fitted with a single channel, battery-operated data logger. An additional three, 20 mm Elster V100 cold-water meters with the same type of data logger were installed to monitor sub-meter irrigation and garden tap volumes, as well as rainwater yield. The metering arrangement also allowed determination of the combined rainwater volume supplied to the toilet and washing machine. The loggers recorded on a daily time-step basis and greywater volumes were estimated from indoor volumes used.

Monitoring at CS2 was undertaken between February and October 2012 to assess the contribution of rainwater and greywater reuse in meeting total water demand. As the monitoring period lasted only nine months, the results were annualized on the basis of comparable months with similar seasonal conditions.

CS3 is a three-bedroom, two-bathroom, detached house on a 700 m^2 block in Hilton, Perth. It was built in 2013 with dual plumbing for both rainwater supply to all indoor uses and greywater collection (excluding the kitchen sink and dishwasher), and water-efficient plumbing fixtures throughout. A data dashboard with real-time user feedback on water use by source (as well as various other household operating parameters, such as electricity and gas use) was also installed to aid responsible consumption patterns.

The property was serviced with rainwater for all internal demands – i.e., potable and non-potable – with mains-water back-up, with the dual plumbing to non-potable demands intended to provide flexibility (e.g. if future occupants want to use rainwater for toilets and washing machine only). Garden demands were serviced by both greywater and groundwater.

The greywater diversion device was the *GreyFlow PS-Two Stage* by Advance Wastewater Systems and operated on the same principles as that at CS2. Groundwater was extracted via a 25 m deep borehole fitted with a variable speed, submersible pump.

Rainwater was stored in an 18,000 L above-ground, corrugated steel tank with the overflow diverted to a soakwell. A pressure-switch activated pump was connected to the tank, and a 90 L pressure-chamber vessel fitted to reduce pump start-up by meeting small demand events. Pressurized rainwater was supplied for all internal uses via a mains-water back-up valve, and water was treated by two-stage filtration and UV disinfection.

Three separate 20 mm Elster V100 cold-water meters were fitted to determine mains-, rain- and grey- water volumes, with a proprietary in-line spun polyethylene filter installed before the meter on the greywater line to inhibit meter fouling. Groundwater abstraction volumes were recorded using a 40 mm flow meter (MT-EX 40). Sub-metering was also undertaken on the lines supplying garden taps and top-up via the greywater system, using 20 mm Elster V100 cold-water meters. A Mercoid Series SBLT2 submersible level sensor was installed in the rainwater tank to record tank

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volumes. Watt meters were installed on each of the power circuits supplying the greywater, groundwater borehole and rainwater pumps to determine the energy intensity of the water sources. All meters and sensors were connected to a multi-channel data-logger, for recording and with real-time user feedback available to the householder via a web portal accessible from personal smart devices (phone and tablet).

Monitoring of CS3 was undertaken between January and December 2015 to assess the contribution of rainwater and greywater reuse to meeting total water demand, and whether groundwater abstracted for irrigation was replenished by local recharge.

RESULTS AND DISCUSSION

Figure 3 shows results from the case studies, including measured and estimated water use by source – rainwater for indoor and outdoor, greywater for outdoor, and mains-water for indoor and outdoor uses. At CS3 groundwater was used in the garden and there was no outdoor need for rainwater or mains-water. The figure includes comparisons with the suburb and metropolitan Perth household averages, with and without supplies from the unconfined aquifer. Water from the latter is used for garden irrigation in summer, when there is little rainfall. Householders with groundwater supplies are allowed an extra day per week for garden irrigation, but no watering is allowed in winter even with groundwater.

The use of rainwater indoors reduced but did not remove dependence on the mains supply, in the case studies, with the infrastructure installed and various water needs. In principle, in CS3, mains water use could be eliminated, if sufficient rainwater was kept until the later part of the dry summer season. This would require restraining rainwater use for outdoor irrigation, using groundwater instead, and the balancing of excessive groundwater use against the risk of storing too much rainwater ahead of the next rainy season. The latter would result in non-optimal use of collected rainwater. Advanced irrigation controllers connected to online weather forecasting would assist with water demand management.

The 18,000 L rainwater storage tank could also be enlarged to reduce dependence on mains-water, although modeling shows that the increased investment required is not justifiable because water use in winter – the rainy season – was readily satisfied (Figure 4).

In CS1 and CS2, where there was no groundwater abstraction, the use of rainwater indoors instead of mains-water and of greywater outdoors, reduced annual mains-water consumption compared to both the suburb and wider Perth region averages.

Water savings progressed from CS1 to CS2 (retrofitted houses) due to opportunities that presented for retrofitting, as well as learning of lifestyle-related water uses (e.g. garden landscaping using plants with low water consumption). CS3 was a new house built intentionally with water conservation in mind.

The unconfined aquifer in Perth can be considered natural rainwater storage and abstraction from it as indirect rainwater harvesting. Modeling showed that the amount of groundwater abstracted at CS3 (86 m^3) was less than the rainwater recharge to the aquifer beneath the property (199 m^3), so water self-sufficiency can be fully satisfied.

The annual operating costs of rainwater, greywater and garden borehole systems are $A335 for CS1, $A270 for CS2 and $A593 for CS3. The annual savings from reduced mains-water use are $A176, $A102 and $A396, respectively. At present mains-water prices, it is clearly not economical to retrofit a house in Perth for indoor rainwater use, and outdoor grey- and groundwater use. This is widely practiced in Perth, however, because of legislated restriction of mains-water outdoor use to twice per week. The use of lower cost greywater diversion devices and lifestyle changes (including garden design to use greywater irrigation) could improve the economics. Recent increases in water tariffs since this analysis will have improved the economics.

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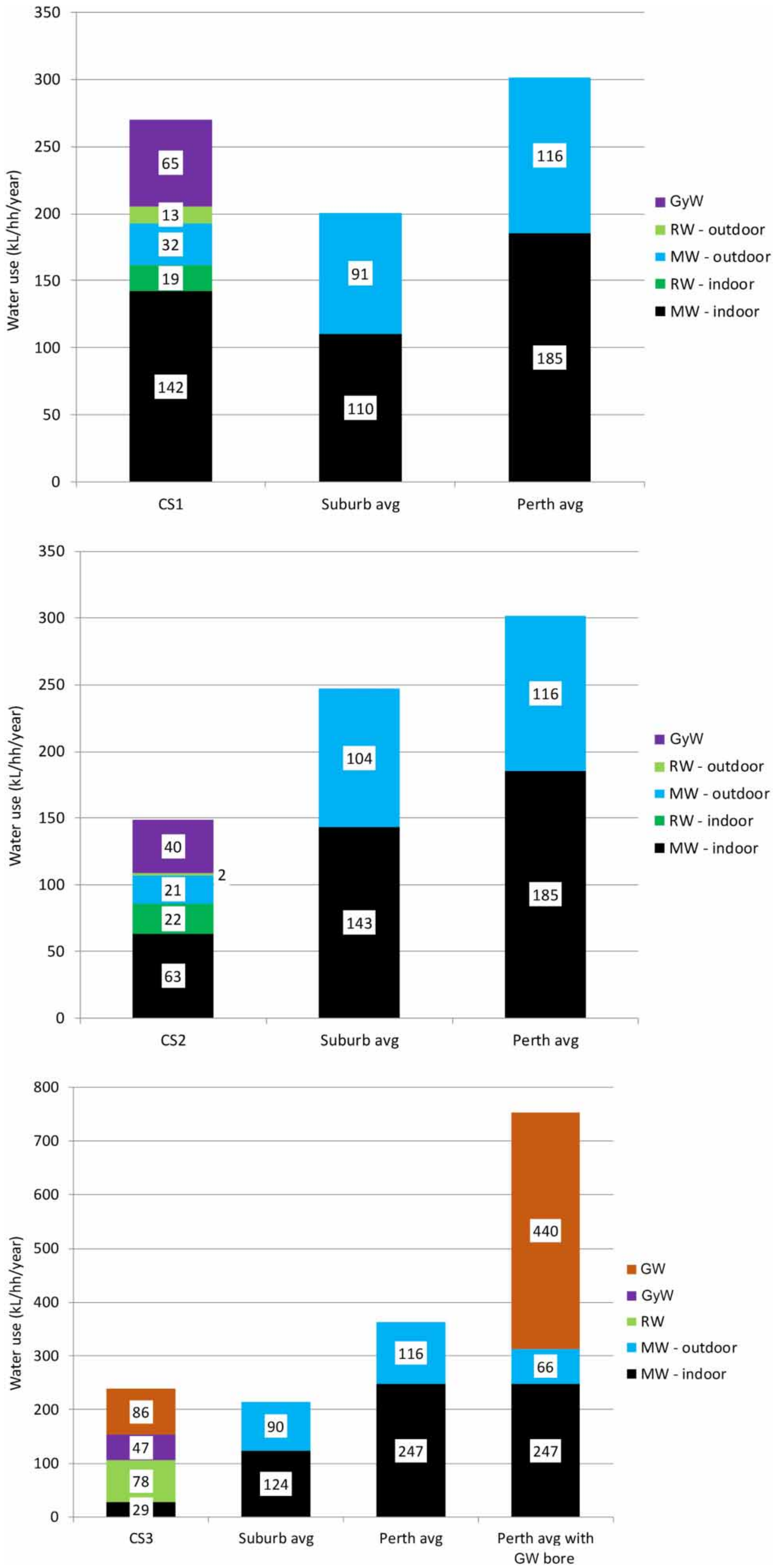

Figure 3 | Water use by source for (top to bottom) CS1, CS2 and CS3. GW = groundwater, GyW = greywater, RW = rainwater, MW = mains-water.

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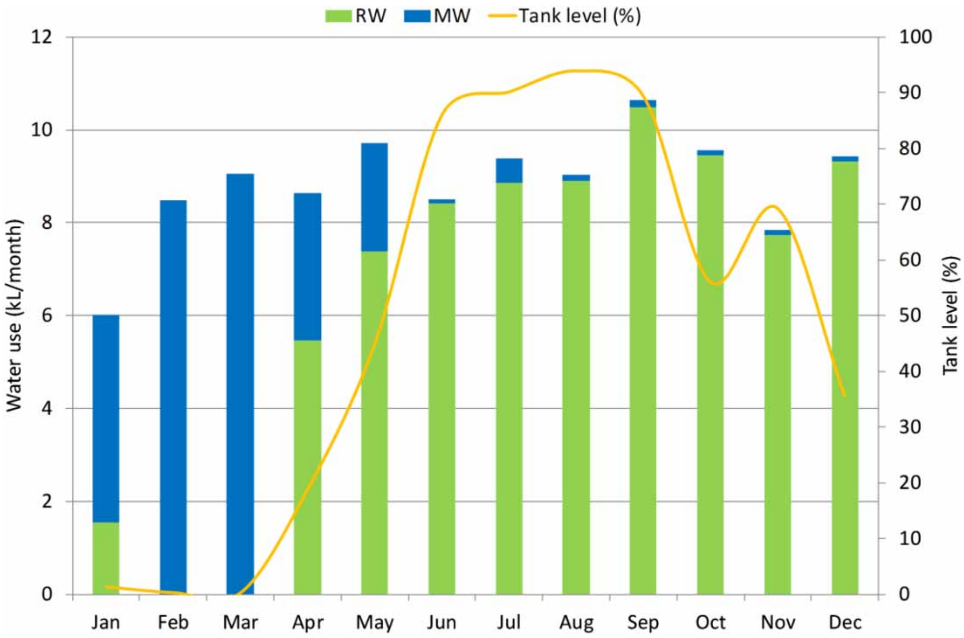

Figure 4 | Indoor mains- and rainwater use at CS3.

For those who wish to be independent or minimize mains-water dependence, the investment and operating costs may yield an increase in house value. This can be considered in the same way as investing in, say, a marble work-surface that would increase the resale value of the house. A recent study showed that installing a rainwater tank increased resale value by more than the tank's cost (Zhang *et al.* 2015).

CONCLUSIONS

Water auditing is a practical tool for assessing household water sustainability under various supply and use scenarios. Its application to three case studies in a city with a Mediterranean climate and a shallow aquifer has shown that it is possible, in principle, to supply indoor and outdoor uses solely from rainwater. Greywater may be used to supplement outdoor use. Such changes are not operationally economic in the cases studied under current conditions, but the new water infrastructure can enhance a house's resale value. If extra on-site water infrastructure is installed at broad-scale across the metropolitan area, it could result in deferred augmentation of the city water supply, for example, expensive seawater desalination plant.

The water auditing approach and water balance model from CS3 is to be extended to a new trial with 50 households across the City of Fremantle, WA (City of Fremantle 2018). The on-site water infrastructure is fitted with NB-IOT smart meters at each household, a water balance model established for each household runs in real-time online, and a dashboard displays water use to occupants in relation to a future urban water trading study. The trial will test the effective deployment of home rainwater, borehole and greywater systems for better mains- and groundwater management, and could result in greater water use reductions than what is achievable with restrictions.

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