Rainwater harvesting for drought management and stormwater control in the San Francisco Bay Area

Réutilisation des eaux pluviales pour la gestion de la sécheresse et le contrôle des rejets de temps de pluie dans la baie de San Francisco

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RÉSUMÉ

Les systèmes de récupération d'eau de pluie (SRP) sont rarement utilisés dans la région de la baie de San Francisco (SFBA), car les avantages sont perçus comme étant faibles. Toutefois, en 2015, en Californie, la sécheresse et la pollution engendrée par les rejets d'eaux pluviales, ont conduit à un regain d'intérêt pour d'autres systèmes de collecte d'eaux pluviales. Contrairement aux études de SRP traditionnels, qui utilisent une évaluation annuelle, cette étude décrit une évaluation à l'échelle des ménages, en utilisant une approche « temps-série » basée sur 20 ans de données de précipitations. Les résultats sont présentés à partir d'un modèle de simulation, lequel délivre des résultats en termes d'efficacité de l'eau (à savoir les économies d'eau annuelles), et le contrôle des eaux pluviales (réductions annuelles, et les pics de décharge des eaux pluviales). Le projet fournit une évaluation des possibilités offertes par la SRP comme outil pour soutenir la SFBA, afin d'atténuer les menaces associées à l'augmentation de la population, au changement climatique et, finalement, à un manque de ressources traditionnelles en eau.

ABSTRACT

Rainwater harvesting (RWH) systems are infrequently used in the San Francisco Bay Area (SFBA) as the technology has low perceived benefits thanks to the region's Mediterranean climate. However, the 2015 California Drought and pollution from stormwater discharges have led to a renewed interest in RWH and other alternative water systems. In contrast to traditional RWH studies that use a short-term, single year assessment method, this study describes an evaluation of RWH at a household scale using a time-series approach based on 20 years of rainfall data. Results are presented from a simulation model that is under development to enable RWH systems to be evaluated in terms of water efficiency (i.e. annual water savings) and stormwater control (i.e. annual and peak stormwater discharge reductions). The paper provides an evaluation of the opportunities presented by RWH as a tool to support the SFBA to mitigate the threats associated with population increase, climate change, and ultimately a lack of traditional water resources.

KEYWORDS

Alternative water systems; Drought, Rainwater harvesting; Source control; Stormwater management

1 INTRODUCTION

California’s growing population (38m in 2015), high agricultural output ($46b in 2013) and high residential water demand (175 l/c/d) exert significant pressures on its water infrastructure. The seasonal nature of precipitation, with rain largely occurring in winter months, poses a threat to the reliable supply of potable water, especially when winter precipitation in key watersheds is below average (Pacific Institute, 2014; US Census, 2015; CDFA, 2015). Dry winters since 2011 have led to a growing concern over the availability of water resources (Hayden, 2015). Estimates show the current drought has seen a shortfall in rain equivalent to a whole year’s precipitation (Savtchenko, 2015). The 2015 California Drought has been widely reported and its impacts continue to mount (State of California, 2015). However, El Nino’s recent shift is anticipated to provide the 2015/16 winter with higher than average rainfall (Savtchenko, 2015). Clearly, *hoping for above-average rainfall* does not represent a robust water management strategy. Water infrastructure that is unable to tolerate fluxes of water availability is unlikely to be defined as robust, reliable and resilient. Perhaps such a circumstance represents the antithesis of the resilient water infrastructure which developed regions of the world now strive for (Butler *et al.*, 2014).

The San Francisco Bay Area, (SFBA) has grown rapidly from 1,000 people (c1850) to a population of approximately 7m, 18% of California’s total. Water resources are chiefly (85%) provided by large water transfer systems with downtown SFBA fed from the Hetch Hetchy catchment, 300km away in Yosemite National Park. Berkeley and Oakland are supplied by the Mokelumne Aqueduct (150km) which reaches from the Sierras Nevada mountains. The 2015 Drought has seen reservoirs depleted and added to the political pressure associated with water use. Consequently, there is added support for technical solutions to support a reduction in potable water demand. In 2008, the San Francisco Public Utilities Commission (SFPUC) declared that alternative water systems (AWS) capacity would be developed to satisfy a demand of 38,000 m^3/day. Following this, design standards and policy shifts have applied pressure on property developers to incorporate AWS to provide service water for WC's, urinals and irrigation systems (Kehoe *et al.*, 2014). In contrast, other developed countries experiencing drought have seen significant rainwater harvesting (RWH) uptake alongside centralised measures such as desalination and water transfer projects (Burns *et al.,* 2014). With little evidence of support for RWH in the SFBA, this paper seeks to identify reasons for low uptake by answering the following questions: 1) Is it too dry in SFBA to harvest rainwater for household WC use? 2) Could RWH contribute to sustainable stormwater management for the SFBA?

Traditional RWH systems divert rainwater intercepted by roofs and store it in above or below ground tanks. The water is pumped back into the building for use in non-potable applications such as WC flushing, washing laundry and irrigation systems. A typical configuration is further described in Fig 1. Significant research (Ward et al., 2010; Roebuck *et al.,* 2011) has investigated the trade-offs between tank size and water efficiency. Design standards and guidance are available throughout much of the developed world (California, UK, Germany etc.) Existing design tools typically allow a single year’s rainfall data to be used to size RWH tanks based on an assumed demand. However, it is recognised that this practice gives a limited insight into the long term benefits of RWH. It is suggested that a time-series analysis over longer simulation periods and with the ability to include future weather/climate scenarios represents a more comprehensive method (Lash et al., 2014). Furthermore, there is increasing interest in the ability of RWH systems to manage stormwater discharges (which can often contribute to sewer flooding and combined sewer overflow spills). This study focusses on the investigation of RWH systems at a plot scale in terms of their ability to reduce water demand and mitigate stormwater discharges within the SFBA.

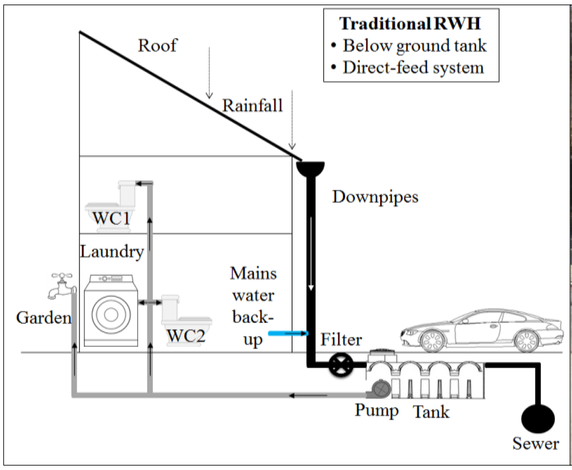

Fig 1. A traditional RWH configuration.

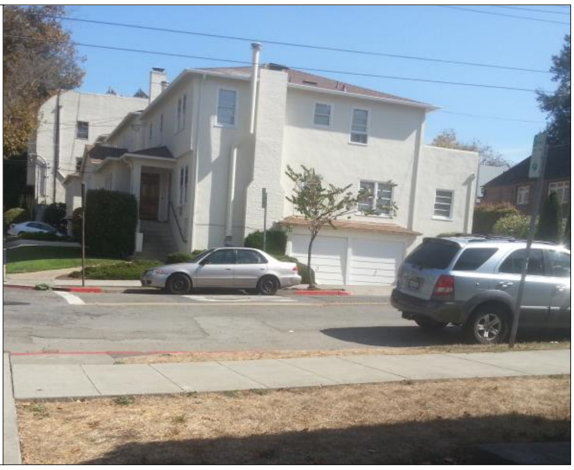

Fig 2. Typical house in Berkeley, SFBA.

2 METHODOLOGY

The following objectives have been defined: 1) Model rainwater demand, rainwater availability and rainwater discharges from a RWH system installed at a typical property in SFBA. 2) Evaluate the benefits of the RWH system in terms of reduced water demand and stormwater discharges at a daily and annual time-step using a 20 year time-series dataset.

2.1 Rainwater Simulation Input Data

Precipitation data was obtained for a rain gauge in Berkeley (within SFBA) for the period 1985-2015 (NOAA, 2015) and processed to remove years with incomplete data (2011-13, 2003, 1990-93, 1988-89). A time-series of the remaining 20 individual years was defined and the daily records of precipitation used to drive simulations of rainwater availability (using well-established equations). Multiple simulations were run with a range of tank sizes to identify tank levels, water demand met and overflow volumes for each day of the 20 year dataset.

2.2 Household Characteristics

Following a site visit, a representative house was selected for appraisal in the study as illustrated in Fig 2. The characteristics in Table 1 were defined to enable the RWH simulations to be performed.

Table 1: Summary of rainwater simulation input data

Parameter	Data used in modelling	Justification / reference
Roof area	100m^2	Measured on site.
Occupancy	4 persons	Assumed (e.g. family house).
Rainwater Demand	120 l/house/day	Occupancy x 5 flushes x 6 litres/flush.
Rainfall	20 year data set, local rain gauge	NOAA 2015.
Runoff coefficient	0.9	10% losses assumed.
First flush volume	First 5 l/day	Filter loss allowance.
Model time-step	Daily	Best data available at this rain gauge
Discharge steps within simulation model's rainwater tank	1) Rainfall volume for day defined; 2) Losses removed; 3) Rainwater added to tank; 4) Overflow volume identified; 5) Demand withdrawn from tank; 6) End of day tank level defined; 7) Repeat for next day.	*Yield after spillage* gives a more conservative (lower mean rainwater availability and higher mean stormwater discharge) than yield before spillage algorithm. (Roebuck *et al.* 2011)
Simulated RWH tank volume	Range: 0-10m^3 at 0.5m^3 steps	A range of available tank sizes was tested.

3 RESULTS AND DISCUSSION

Precipitation data supported anecdotal evidence that rainfall in SFBA experiences high seasonal variation. Over the 20 year dataset, 81% of 659mm annual average precipitation occurred during winter (Nov-March). Consequently, simulations indicated that RWH systems with larger tank sizes were able to outperform smaller tank sizes in terms of both satisfying water demand and through achieving a reduction in stormwater discharges as illustrated in Fig. 3. The range of minimum, mean and maximum values has been plotted to illustrate the variability associated with rainfall during the 20 year assessment period. As exemplified in Fig. 3, the annually aggregated data for the simulations shows that RWH can achieve significant reductions in water demand and stormwater discharges. However, sewer flooding and combined sewer overflows typically occur during short storm durations. The simulations were re-analysed using a daily time-step to define the minimum, mean and maximum stormwater discharges under two scenarios: 1) A house without RWH (0m^3 tank selected), and 2) A house with RWH (5m^3 tank selected). For the 20 years modelled, Fig. 4 illustrates the results which show that mean stormwater discharges are notably reduced, however, the annual maximum discharge rates are less well controlled by the RWH system.

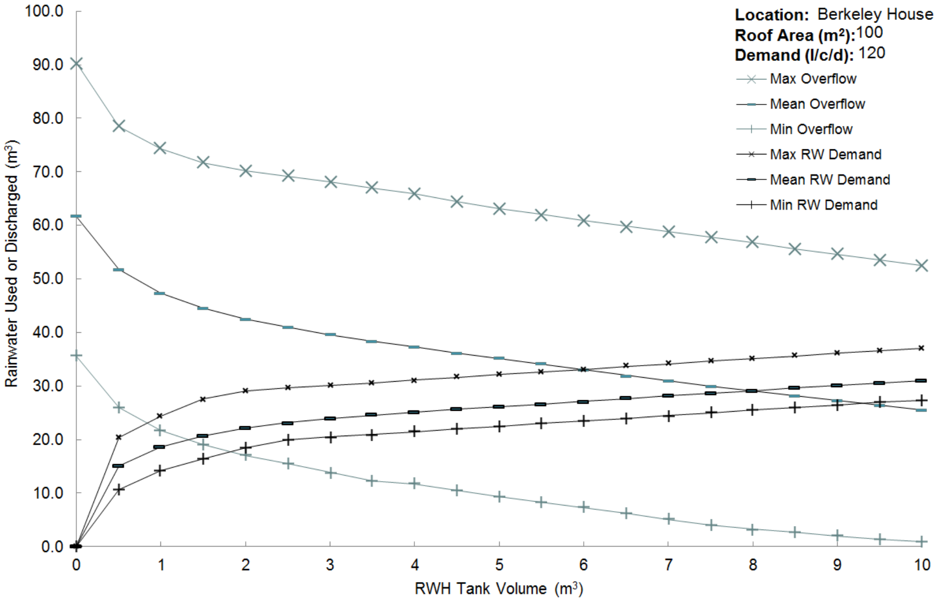

Fig 3. Annual RWH demand satisfied and total stormwater overflows for tank sizes: 0-10m^3 (max, mean and min from 20 annual simulations)

4 CONCLUSIONS

In relation to question 1, anecdotal evidence that RWH is not a suitable technology in SFBA was found to be poorly founded as a 5m^3 RWH system was able to deliver 26.1m^3 (60%) [range 22.4-32.1m^3/year (51-73%)] of WC demand over the 20 years assessed. 5m^3 RWH installations have been demonstrated to provide savings in excess of 10% of total household water demand. Their wider deployment could be considered as an alternative water supply system in SFBA.

Regarding question 2, when stormwater flow reduction was evaluated over 20 years, the 5m^3 RWH system was found to reduce annual average stormwater discharges by 26.1m^3 [range 21.9-32.6m^3]. Furthermore the discharge rate for the annual maximum storm (i.e. the largest annual storm) was reduced by 18% on average [range 0-56%] with some storms seeing up to 5m^3 discharge reductions (i.e. tank was empty at start of large storm). The study has exemplified the opportunity for RWH systems to be installed for WC flushing (rather than irrigation demand) as the WC demand is consistent throughout the year, whereas the household irrigation demand is strongly correlated with low rainwater availability. Further work is warranted to investigate the use of longer time-series data sets, in multiple locations alongside the development of future climate change scenarios that reach beyond the events recorded at local rain gauges.

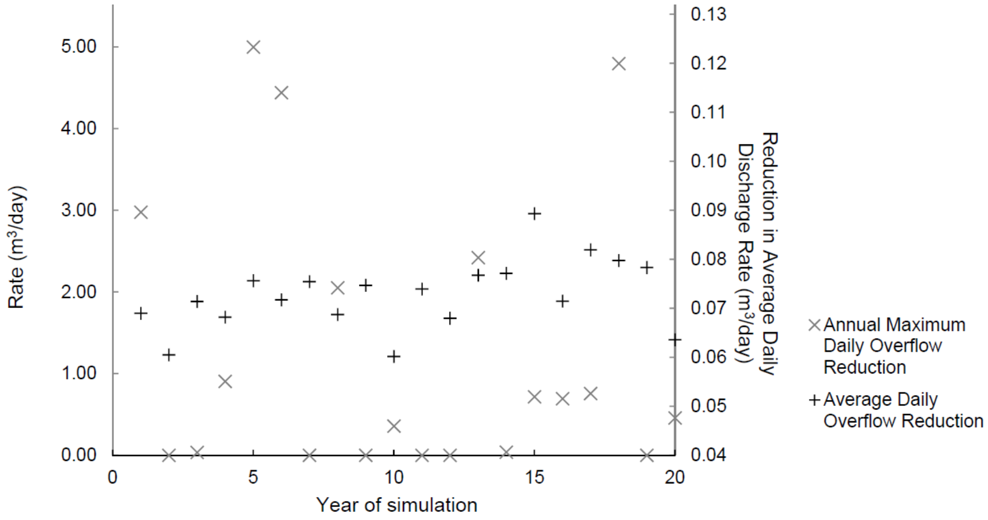

Fig 4. Summary of average and annual maximum daily discharges with and without RWH installed.

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