Urban resilience: potential for rainwater harvesting in a heritage building

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Abstract: Population growth and climate change are imposing challenges on the built environment and urban communities, including managing growing water demand. The Wellington water supply network is vulnerable not only to rainfall variation but also earthquakes where it could struggle for water to fight fires post-quake. Rainwater harvesting for greywater would also be beneficial under water scarcity. Historic buildings, an important part of the city's built environment, can contribute to sustainable development while also reducing water demand. This paper presents a rainwater harvesting study on the Heritage New Zealand Pouhere Taonga Category 1 'Old Government Building'. The 145 year old timber building houses the Victoria University of Wellington Faculty of Law, with about 2,000 students and staff. In addition to the challenges due to heritage requirements, the environmental, economic and social benefits are examined. These include resilience to flooding and climate change, a backup plan for building and city fires, water cost reduction, and regional sustainable water management. The recommendations which, while directed at this building, will be appropriate for consideration in other heritage buildings. It must not be forgotten that rainwater is a valuable natural resource that creates a number of opportunities and benefits for the city and communities.

Keywords: historic buildings; water management; urban resilience; climate change.

1. Introduction

Population growth and changes in weather patterns due to climate change are imposing challenging times on the built environment and urban communities, including growing water demand. Cities concentrate approximately 53% of world's population (Nachshon et al., 2016, p. 398). According to Bint (2012), New Zealand demand for potable water is rapidly increasing on domestic and non-domestic buildings, as well as for irrigation and recreational uses. However, many water catchments are already over allocated or close to full allocation, so future scenarios predict water scarcity in many areas in the country. In Wellington, the water supply network is vulnerable not only to rainfall variation but also earthquakes.

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In order to create resilient and sustainable cities, the built environment needs to adapt and reduce its demand on water supplies. If used wisely, buildings can provide an additional source of water. The building's roof area can be used for rainwater catchment coupled with water reuse systems represent favourable components which can help reduce the city water demand and wastewater treatment in dense built up areas. The continued use of heritage buildings also contributes to cities sustainable development. Good heritage asset management can contribute to reduce its water demand while maintaining its community significance.

This paper firstly describes the main key drivers of collecting and reusing rainwater, and then explores a preliminary feasibility study of implementing a rainwater harvesting system into the historic Old Government Building, a Category 1 listed building (Figure 1). Old Government Building, built in 1876 in the Italian Renaissance revival style, is New Zealand's largest wooden building. It once housed the entire administration for the New Zealand Government. Currently owned by Heritage New Zealand Pouhere Taonga (HNZPT) and managed by HNZPT Central Regional Office, the building was strengthened in 1931, when the chimneys were removed and replaced by lighter structures and fully restored from 1994 to 1996. Since 1996, it has been leased to the Victoria University of Wellington and is used for the Faculty of Law.

Figure 1. 'Old Government Building' - VUW Law School. Source: https://blog.doc.govt.nz/.

2. Key drivers

Rainwater is a valuable natural resource and its use can create a number of opportunities and benefits for cities and communities. The rainwater harvesting capacity and the intended reuse depend on both geographic location, and whether there is a centralized or decentralized city water supply. In centralised systems like in Wellington, the rain harvesting offers resilience to disruptions from natural hazards and from breakdowns in the main supplier system (Kettle, 2010, p. 84).

Internationally many governments are creating policies encouraging water reuse in dense urban areas. The New York City Environmental Protection Agency (EPA) has water conservation and reuse grants providing property owners with incentives to install fixture retrofits and other water efficiency technologies, such as on-site water reuse systems. For new and existing buildings with successful on-site water reuse systems reducing the building's water consumption by at least 25%, there is 25% water and wastewater fee discount (NY City Environmental Protection, 2020).

Most buildings in Wellington have connection to a reticulated, treated main water supply system (Wellington City Council, 2020; Wellington Water, 2020), but they could significantly lower mains water usage by installing a rainwater harvesting and reuse system.

Climate issues described in New Zealand climate reports (Ministry for the Environment, 2018; Pearce, 2017) show an increase in temperatures by 3°C, a reduction up to 15% rainfall and more extreme rainfall events in the Greater Wellington Region by 2090 – all leading to an increasing risk of drought in the Wairarapa region, which is the main area that supply water for Wellington, and an increase in local flooding. The historic Old Government Building is situated in a 1 in 100 year flood zone according Wellington City Council (Figure 2), which could compromise both the building conservation and site protection in the case of more extreme rainfalls. Rainwater harvesting can potentially decrease stormwater runoff, thereby helping to reduce local flooding and creating more resilient urban areas (Wellington Water, 2019).

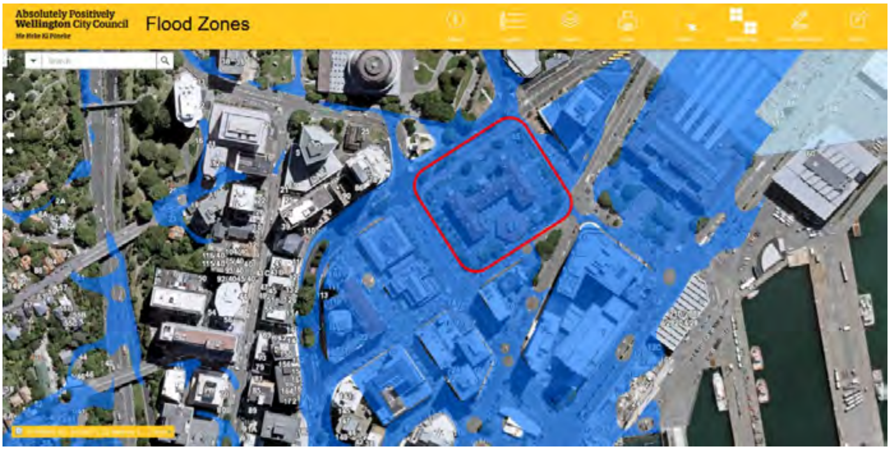

Figure 2. Flood zones in Wellington. (Source: https://www.wellingon.govt.nz – Maps – Flood Zones).

Beyond climate change, the other main driver relates to the vulnerability of Wellington's water supply network. The city is particularly vulnerable due to its physical isolation east of Wellington fault, concentration of population and lack of access to alternative supplies (Beban et al., 2013, p. 15). In the case of an earthquake of 7.5 or stronger, some suburbs and the CBD could be without water for more than 100 days (Wellington Water, 2020). Wellington would also struggle for enough water to fight fires on post-quakes. According to a Radio New Zealand news (Towle, 2020), a GNS report reveals that the Wellington Water would isolate the city's reservoirs, which would then be prioritised for drinking water, stopping their use for firefighting. Therefore, there is a great opportunity for rainwater reuse for emergency water supply. In this sense, harvesting rainwater would be beneficial for fighting possible fires in the wooden building, concurrently as a backup water storage for the building occupants.

Rainwater reuse in a heritage building can create a conscious attitude towards resilience, protecting and enlarging the life of an urban historic area. Even more, it can add new contemporary values to the historic building. For instance, the Venice city management plan highlights the importance of considering broader and modern aspects on the management of heritage assets (Ursino and Pozzato, 2019). The list of benefits of reusing rainwater represent economic, social and environmental gains, such as reducing water bills, protecting remaining natural water sources, reducing infrastructure operating costs, water emergency supply, resilience to flooding areas and other climate change implications.

3. Preliminary feasibility study

The first step in developing an on-site water use plan is to verify if the roof has enough capacity for collecting rainfall to meet the building's needs. Given the 2,500 m^2 of roof area located in a site without major interferences, such as being surrounded by high, dense vegetation, the building has a good potential for harvesting rainwater. This section firstly presents the method for calculating rainwater collection and reuse, and then it also explores realistic end uses compared with the building's current water usage.

3.1. Rainwater harvesting potential

The design aspect of rainwater harvesting involves optimum sizing of the components, and the amount of water that falls determine the volume of storage tanks required for the different uses of rainwater (Haq, PEng, 2017, pp. 51–54). The formula (1) that calculates the harvesting potential (P) in litres, considers the roof area in the horizontal plan in m^2 (A), the mean monthly rainfall levels (L) in mm taken from NIWA records (NIWA, 2020) , and the runoff coefficient (RC) selected from generic lists based on the degree of imperviousness and infiltration capacity of the drainage surface. Estimates consider that roof RCs are within the range of 0.7 - 0.95 for relatively frequent storms. Rooftop runoff water quality is dependent on both the roof type and the environmental conditions of both the local climate and atmosphere pollution (Farreny et al., 2011, p. 3246) .

$$P = A \times L \times RC \tag{1}$$

Where:

P = Harvesting potential (litres); A = Plan roof area (m^2); L = rainfall (mm); RC = runoff coefficient.

The roof area was calculated based on existing plans and a roof report prepared for HNZPT (Ermenyi, 2020) that informed the current roof conditions, materiality, dimensions and angles of the pitched roof. The steel roof was installed in 1996 with a standard warranty of 15 years, and this inspection concluded was that the roof was still performing adequately (Pace, 2020).

The roof area is approximately 2,500 m^2 in the horizontal plan. The main corrugated, galvanized steel, pitched roof has an approximate angle of 22^o which gives a generic 0.8 runoff coefficient, due to the imperviousness from the roof material (Farreny et al., 2011) . Wellington average monthly and annual rainfall levels (mm) were taken from available NIWA reports (NIWA, 2020) for the 1981-2010 period with at least 5 complete years of data. The potential is almost 2.5 million litres per year. Figure 3 shows the potential monthly water harvest and it is noticeable that the highest potential is during winter months. These results only consider the main existing building, but not the annex building at the back of the site.

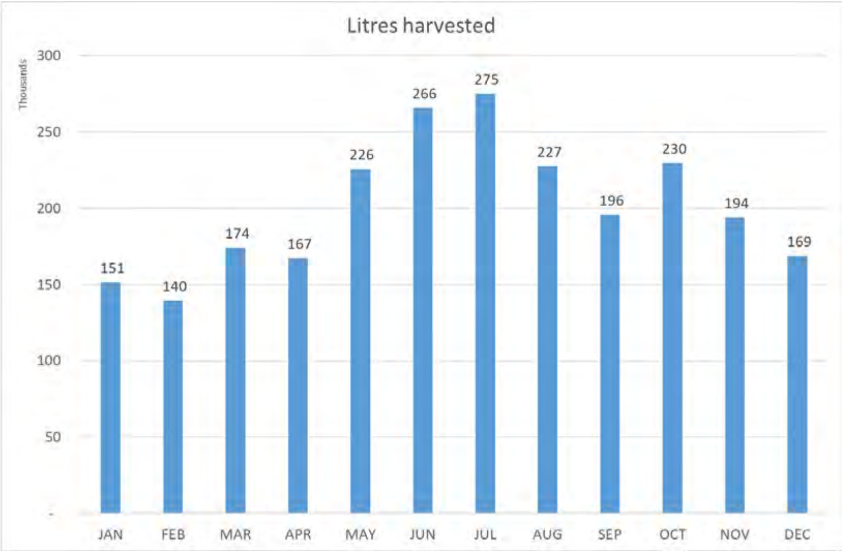

Figure 3. Monthly rainwater harvesting potential (‘000 litres).

3.2. Building water usage

Beyond estimating how many litres of rainwater the roof can collect, it is essential to understand the water use in order to identify potential savings. To estimate the water consumption two methods were used: firstly overall water records from 2018 and 2019; and secondly regular readings of the building’s water meter during February and March 2020. These readings enabled the understanding of end uses and potential savings, including the minimum building daily water use. The building was washed during the period of meter readings, providing useful data. The garden irrigation system was not working, so it was not possible to confirm the irrigation water use. Toilet flush water use was estimated by comparisons from the literature on the average water use of different appliances.

The typical end uses of rainwater or greywater reuse include landscape irrigation, wash applications, and toilet and urinal flushing (Kapiti Coast District Council, 2017, p. 6) . Discussions with the Water Wellington engineers helped understand the potential water end uses. The concept was not to obtain potable water, as it would require a special and complex system of additional filtration and disinfection treatment. In addition, it is not recommended for potable water reuse in the urban setting due to possible health risks and the large size tanks (Kettle, 2010, p. 83). Therefore, the list of potential rainwater end uses would be for washing the building (normally twice a year, but currently only once a year due to drought); watering the gardens; toilet flushing, and for emergency non-potable water supply.

3.2.1. Victoria University of Wellington (VUW) records from 2018 - 2019

The university has a sustainability dashboard in order to monitor and control the usage of energy, gas and water of university buildings. Given these records, it was possible to assess information from the past two years average water use and identify different water patterns during the year (Figure 4).

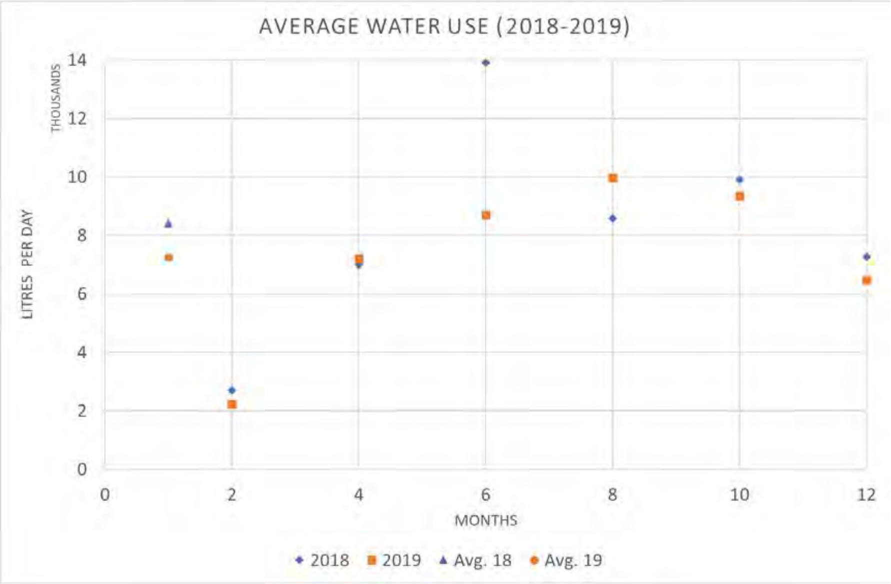

Figure 4. Average water use in 2018 and 2019.

The long term records shows between April to October (first and second teaching trimesters), water usage is higher probably due to high building occupancy. Comparing overall use (Figure 4) with rainfall patterns (Figure 3) reveals potential for rainwater reuse, as the highest water use months are also when rainwater potential is higher. The average water use during the last two years was about 8000 litres per day but increased from 2.6 to 3 million litres per year, close to the roof potential of 2.5 million litres peryear.

3.2.2. *Water meter readings*

Water meter readings were carried out to compare with the longer term records and to understand the overall usage. During February - before the first trimester resumed - and March - during the first trimester, but partially in the Covid-19 lockdown - the meter was read twice a day (9 a.m. and 7 p.m.) to record the day and night measurements, also to understand the week and weekend differences (Figure 5).

The Figure 5 shows, like the long-term records, that there is a noticeable difference in water use between the pre-term and the trimester periods. This difference is especially seen during the weekdays when the building is mostly occupied by students and staff. Another important figure represented in the graph is the weekend night use, when the building is expected to be largely unoccupied. However, there is still an average of 90 litres per hour consumption during the weekend night in the pre-term period representing the building minimum water usage. This result is based on a preliminary assessment and suggests longer term monitoring should be carried out in order to have refined results in a future stage, but still shows that there is a potential to reduce the minimum water consumption. The meter readings also confirmed that the meter daily average matches with the average longer-term daily use of 8,000 litres.

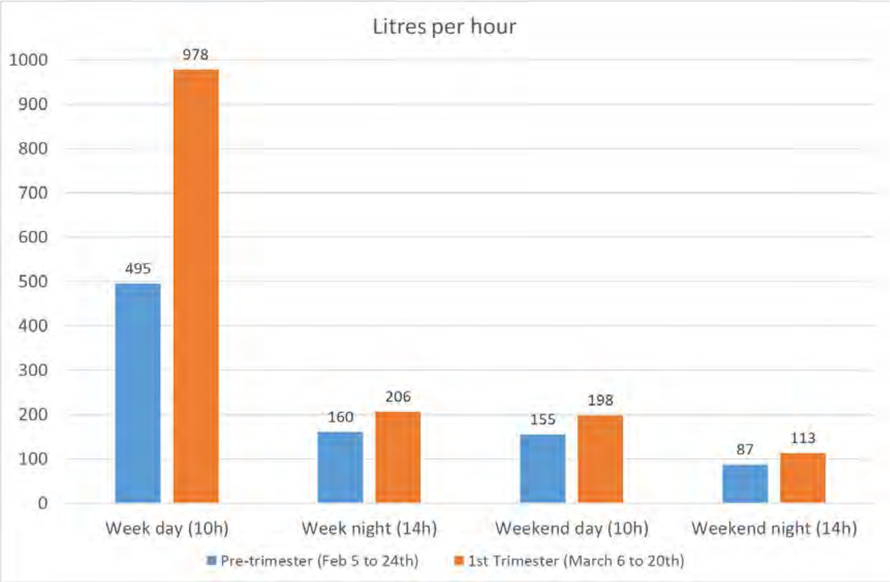

Figure 5. Litres per hour from February and March meter readings.

Readings were also made for one week when the building was being washed, finding washing the building once a year uses approximately 40,000 litres.

3.2.3. *Toilet flush*

The toilet flush systems represent an opportunity for improvements, as they can be responsible for leakage faults. Different models have different toilet flush duration, resulting in different water consumption. A comparison method was used to roughly estimate the amount of water used by each flush system in the building. Firstly the different flush systems were identified (11 cyclically flush wall pod urinals and 58 single flush cistern or in-line toilets), then the recorded consumption from the literature (Bint, 2012, pp. 106–109) was used to calculate the overall yearly use (see Table 1 which also gives the assumptions). For example, the single flush toilets over a 52-week occupation used approximately 1 million litres per year.

Table 1: Building toilet flush systems and overall usage.

Number and model of flush systems	Litres per hour used (Bint, 2012, pp. 106–109)	Total litres per year (approximate)
11 cyclically flush wall – pod urinals	(2 flushes per hour of 4 litres) 88 litres per hour:	700,000 litres per year
58 single flush (cistern or in-line) toilets	(5 to 11 litres per flush) 464 litres per hour.	52 weeks considering different occupancies 1,000,000 litres per year

4. Analysis of findings

This preliminary study identified potential water savings given the significant minimum usage figure from weekend nights, as well as potential for the use of rainwater for washing the building, toilet flushing and garden irrigation. The estimated water savings are listed below.

- Water use for washing the building: 40,000 litres a year.
- Estimate toilet flush consumption: 1.7 million litres a year.
- Watering lawns or garden irrigation: usage unknown.
- Building minimum water use and possible leaks: there is a potential for reduction of around 800,000 litres a year if appliances are improved.

The analysis shows toilet flushing and building washing use a total of about 1.8 million litres per year, which is less than the harvesting capacity of 2.5 million litres per year, suggesting there is still a great potential for emergency water supply and garden irrigation.

To store this collected rainwater would require approximately 2000 m^3 of underground volume, although further analysis is required to confirm this would be` appropriate. However, it is important to stress that the first action before implementing any rainwater (or reuse) water system is to reduce the water usage by upgrading old and inefficient appliances. For instance, if the toilet and pod urinal flushing systems were improved there would be a decrease in the toilet flushing which might free rainwater capacity for other end uses, such as emergency water supply for other nearby buildings.

In terms of cost savings, taking into account the 2012 Wellington price of potable water of NZ$ 1.715 per m^3 (Bint, 2012) and the yearly harvesting capacity of 2500 m^3, the yearly savings would be around NZ$ 4,300. These savings are not great due to the current low rates of water in Wellington, which does not have variable costs on both incoming potable water and the outgoing wastewater like Auckland(Watercare, 2020). However, beyond the low economic savings that might change and increase in the future, there are other relevant social costs to consider, such as reducing local flooding and providing additional resilience for Old Government Buildings in case of a natural disaster.

5. Discussion of benefits and constraints

The research findings confirm the social, environmental and economic benefits of implementing a rainwater system in existing buildings. It can represent a long-term water and cost savings in a climate change scenario of water scarcity and future increase in water prices, as well improve resilience for the building (and potentially its neighbours) in case of fire or a natural disaster such as earthquake or flooding. The social and environmental benefits for the building, city and region are also important aspects. Another aim of having a rainwater reuse system, and also upgrading water appliances in historic and heritage buildings is promoting them as responsible consumption benchmarks contributing to create thriving and resilient communities (Ursino and Pozzato, 2019).

Nevertheless, implementing rainwater use systems in heritage buildings can be challenging. The proper and critically designed intervention must not interfere at the authenticity and integrity of the heritage asset. In order to maintain the heritage significance, interventions need to be approved by the correspondent protection agencies that will look to ensure the ICOMOS NZ Charter (or in Australia the Burra Charter) principles of conservation are being followed. These agencies will look for solutions that have minimum interference in the building fabric appearance and are reversible ((ICOMOS Australia, 2013; ICOMOS NZ, 2010), but that may not always be possible. Some Australian guidelines even indicate if an above ground tank is installed in a heritage area, it should be located in the rear yard (ABCB, 2016,

p. 44). The upgrades in plumbing systems will require at times intervention in the existing fabric; therefore the solution needs to be carefully designed by a multi-disciplinary team of plumbing engineers and conservation experts.

Another constraint may be the cost investment of a project in this scale. The end uses of a rainwater harvesting system will define the treatment, distribution and storage requirements. Some end uses such as potable water will require a complex filtration and treatment system that incurs in a more expensive initial investment. The use of rainwater for toilet flushing may require adding or upgrading plumbing systems that need to be carefully planned in order to be cost effective solutions. It is important to evaluate the long-term cost benefits and the life cycle cost analysis. Each historic and heritage site need to be assessed individually in terms of potential for intervention, as each will present unique constraints. The research reported in this paper is but a first step towards the future use of rainwater in Old Government Buildings.

6. Conclusions

In order to achieve resilience in urban areas, not only new buildings need to adapt to the new climate requirements, but all existing buildings, including historic and heritage at some degree can contribute to thriving and resilient communities. This paper highlighted the numerous social, economic and environmental advantages of including a rainwater system in a historic area and building, enhancing their preventive protection. Despite possible cost and heritage constraints, it does not set aside the feasibility of implementing a rainwater system in Old Government Buildings.

The preliminary findings suggest that the roof space can collect about 2.5 million litres of water per year that could potentially be used in place of approximately 1.8 million litres of city supply water for washing the building, irrigation, toilet flushing and emergency water supply for fighting fires or other disasters. Moreover, harvesting rainwater can decrease the stormwater runoff reducing the risks of local flooding. The rainwater collection system would require simple measures such as, adding filters to the gutters, a first flush diverter and water storage tanks. However, the tanks would need a more detailed concept and design in terms of minimizing the heritage impact.

Further research on the heritage impact of different system options is recommended following this first preliminary study, as well as a long-term water monitoring for further validation. The feasibility analysis in terms of life cycle cost should be carried out in a second stage in order to understand the most cost effective appliances, for instance if flushing and taps are upgraded, and if plumbing works are required.

Acknowledgements

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