Integrated urban water balance of an eco-building

Etude du cycle de l'eau à l'échelle d'un bâtiment écologique

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RESUME

Le bâtiment écologique de Landcare Research à Auckland, Nouvelle-Zélande a été conçu de façon à minimiser l'utilisation d'eau du service publique, en favorisant l'utilisation des eaux de pluie et aussi de minimiser la production des eaux usées, afin de réduire l'impact sur les eaux naturelles. Cela fut un défi puisque les laboratoires et les serres de Landcare Research utilise une quantite importante d'eau. L'utilisation d'eau du service publique a été minimale grâce au recueillement et la réutilisation des eaux de pluie ainsi que la réduction de la consommation d'eau en utilisant des toilettes sèches. De plus, les toilettes sèches produisent un produit utilisable à partir des déchets et réduit ainsi la production de déchets non traités. La récupération des eaux de pluie à partir du toit réduit l'impacte de l'écoulement des eaux sur le bâtiment. Les autres pertes d'eaux sont les eaux de pluie qui s'écoulent sur le parking. Le parking fait parti du traitement des eaux de pluie par une zone de rétention et un jardin pluvial qui permettent la réduction du volume totale d'eaux et des crus qui entrent dans le système du cycle de l'eau. Les résultats de l'étude du cycle de l'eau bu bâtiment écologique sont présentés avec une discussion sur les données du système, ainsi que le besoin requit par le système et enfin les pertes d'eaux du au système.

ABSTRACT

The Landcare Research sustainable commercial building in Auckland, New Zealand, was designed to have a small demand for mains water and minimal discharge of stormwater and sewage, to reduce its impact on natural waters. This was a challenge given that the core business operations of Landcare Research, such as research laboratories and experimental glasshouses, require a large volume of water. Minimising the use of mains water was achieved by harvesting and reusing stormwater as well as reducing demand, primarily by using composting toilets. In line with the principles of sustainability, the composting toilets produced a useable product from a waste and reduced untreated discharge from the building. Harvesting the stormwater from the roof reduced the impact of runoff from the building. The other key discharge was stormwater running off a carpark. The carpark forms part of a stormwater treatment train including a bioretention strip and raingarden which reduced the total volume and peak flow of water entering the stormwater network. Monitoring results are presented as an integrated urban water balance with discussion about the inputs to the system, followed by the demands placed on the system and then discharge from the system.

KEYWORDS

Bioretention, Compost toilets, Raingarden, Urban water, Water consumption

1 INTRODUCTION

Landcare Research is a New Zealand Crown Research Institute primarily concerned with the terrestrial environment and sustainable development. When Landcare Research chose to relocate to a brownfield site on the University of Auckland's Tamaki Campus, staff wanted to demonstrate how it might be possible to build a new building that was more environmentally friendly than usual. This was made complex by the requirement for research laboratories, glasshouses and housing for the six million or so specimens in the national collections of insects and fungi.

The Tamaki building has been widely acknowledged as a leading example of a sustainable building. In May 2005 it won the Energy Efficiency and Conservation Authority's Energy-Wise Commercial Building award and it also received an "environmental hero" Green Ribbon Award from the Minister for the Environment.

The design considered four waters: mains-, storm-, waste- and natural-. The Tamaki building aims to reduce the demand for mains water and discharges of stormwater and sewage compared to a conventional building, to minimise its impact on natural waters. The building was also designed to be energy efficient and make use of renewable materials and finishes that had a 100-year life.

The design and operation of the building's integrated urban water management systems are presented here as a water balance. Discussion focuses on the input of water, demands for water, and output of water from the system. The building is being monitored to see if its environmental performance measures up to the design intentions. In this paper, the measured operational performance of the building is provided to show what has been achieved and allow comparison of its performance with national and international practice.

2 INPUTS OF WATER

The inputs include rainfall, harvested rainfall and potable water supplied by the city's water mains. Another input is human excrement, but in this building most excrement is composted and so is not combined with water.

2.1 Rainfall

The location of the building in Auckland City, at 36°S in the south-west Pacific, means that summers are warm with high humidity and winters are mild and damp. Rainfall is measured onsite using several 0,2-mm tipping bucket gauges. Data records are complete from 19 January 2005 to date. These are supported by climatic data collected at a weather station just 500 m from the building since December 1992. The city experiences most rainfall in April to September (90–130 mm/month) and moderate moisture deficits (30–90 mm/month) from November through March. The long-term average rainfall is 1200 mm per year (ARC 1999).

2.2 Water supply

The building is connected to the mains water supply. In addition, runoff from the 1526-m^2 roof area drains through a syphonic drainage system to three 25 000-L rainwater storage tanks connected in series. The first two tanks are connected at their base and are in hydraulic equilibrium. The third tank collects overflow. Water is pumped from the two tanks in equilibrium to two smaller header tanks, using electricity supplied by a 400-W wind turbine. A mains backup is available for prolonged dry spells and for fire fighting.

3 DEMAND FOR WATER

The design goal was to improve upon the demand for potable mains water of a typical office building. This was a challenge given that the core business operations of Landcare Research, such as research laboratories and experimental glasshouses, require a large volume of water. Rainwater harvesting, low-flow fittings and composting toilets contribute towards the goal.

3.1 Mains water

The buildings potable water is supplied by the city main supply. The daily consumption of mains water was manually measured, for working days between 19 July 2005 and 5 April 2006. Then in May 2006, a building management system became operational that automatically records the hourly rates of total mains water consumption and volume of mains water used to top up rainwater tanks.

3.1.1 Hand basins, showers and kitchen use

As a potential source of potable water, hand basins, showers and kitchen appliances were required to be supplied by mains water but have low-volume, water-saving fittings to prevent unnecessary wastage.

3.1.2 Purified water for laboratory use

The building also draws on the city water supply for water treated by reverse osmosis (RO), required for laboratory work such as washing glassware and making chemical solutions. The RO treatment process is a large consumer of water because only an estimated 30% (maximum) of the water used in the process is purified. The system has been configured so that the reject water can be sent to the rainwater tanks.

3.2 Rainwater harvesting and reuse

Stored rainwater is delivered to the building from two header tanks. The separate header tanks distribute water to the glasshouses or flush toilets/ urinals. The building management system records the hourly demand for stored rainwater from each.

3.2.1 Toilet system

The first and second floors have seven individual toilet pedestals connected to two Clivus Multrum composting bins. The bins are gravity-fed from the male and female toilets respectively and use no water for flushing. Composting toilets were not suitable for use on the ground floor because the depth of hole needed to house the compost bins would have been below the flood level and very expensive to dig as the building is situated on basalt rock. On the ground floor there are five dual-flush toilets. Manual flush urinals, using rainwater, were installed in the male facilities on all three floors.

3.3 Monitoring results

3.3.1 Ratio of mains water to harvested water

The period of most complete data, 18 August 2006 to 6 November 2006, was used to calculate the ratio of mains to harvested water use. Between 6 p.m. on 7 September 2006 and 1 p.m. on 8 September 2006 a toilet malfunction resulted in leakage of 14,1 m^3 of stored rainwater. This was omitted from the calculation.

A total of 227,7 m^3 of water was consumed during the period analysed. This was made up of 125,1 m^3 drawn from the city water main, 32,4 m^3 of rainwater supplied to the toilet header tank, and 70,2 m^3 of rainwater to the glasshouses. No mains water was used to top up the rain tanks. Thus, the total consumption was made up of 45% reused rainwater and 55% mains supply.

3.3.2 Cost savings by reusing rainwater

Landcare Research is charged NZ$4 per cubic metre of water it draws from the water main, which includes the cost of subsequent wastewater treatment. Landcare Research paid NZ$500 for mains water supplied between 18 August and 6 November 2006. The reuse of rain water saved NZ$410 during the same period. Cost savings would have been greater if the building had been designed with more conventional appliances.

3.3.3 Mains water consumption

The total annual consumption of mains water equalled 879 m^3, for the year ending 1 November 2006. The number of full-time-equivalent (FTE) employees during this period was 80,25, making the total mains water used 11,0 m^3 per FTE per year. The total floor area is 4766 m^2, resulting in a mains water use of 0,18 m^3/m^2 per year.

Many design goals are reported for water use in commercial buildings, but few actual measurements. Measurements have been used by The Department of Sustainability and Environment in Victoria, Australia, to determine a benchmark figure of 50 L per FTE per day (Kyle Garland, pers. comm. 20 March 2003). Based on a 250-day operational year (5 days a week, 50 weeks a year) this equates to 12,5 m^3 per FTE per year. The organisation manages its water consumption, so the figure contains attempts at conservation. The consolidated environmental data for 2001 presented in the 2002 *Corporate Social Responsibility Report* of the worldwide operations of the CGNU Insurance Group (CGNU 2002) provides consumption measurements of 9,2 m^3 of water per FTE per operational year throughout their buildings. Twort et al. (1994) suggest a figure of 65 L per day per employee for water consumption in commercial and institutional establishments. Normalising Twort et al.'s figure for the operational year gives a total consumption of 16,3 m^3 per FTE per year.

Despite the large water demand in laboratories and glasshouses, the consumption of mains water in the Landcare Research building (11,0 m^3 per FTE per year) is similar to or better than measured targets for commercial buildings, including those that have adopted some environmentally sustainable practices. The composting toilets and rainwater harvesting have clearly reduced the demand for mains water.

4 OUTPUT OF WATER

The stormwater and waste-water discharges are the most important in terms of the urban water balance and the potential impact of the building.

4.1 Stormwater

4.1.1 Runoff from the roof

Much of the roof runoff is harvested, so stormwater discharge into the municipal stormwater network is limited. The overflow tank is used to irrigate the site's gardens via a gravity-fed drip irrigator. The water is presumably evaporated, transpired by plants, or recharges groundwater. To provide detention volume during the rainy months, when there is a surplus of runoff water and the gardens do not require much irrigation, the tank is slowly drained to a raingarden.

4.1.2 Stormwater treatment train

A building's carpark is often a major source of stormwater and so the carpark was designed as the first step in a stormwater treatment train. The carpark drains to a bioretention strip, which in turn drains to a raingarden. The water that passes through the raingarden enters the local network of stormwater pipes, which delivers it offsite to a constructed stormwater pond and then to a local stream. The onsite devices are described below.

4.1.3 Design of the carpark

The 761-m^2 carpark was designed as a permeable area and constructed of compacted gravels. The gravel provided some interconnected pore space but had a "slow" (McQueen 1983) infiltration rate. Mean saturated hydraulic conductivity, measured over 48 h using the twin-ring method, and following 48 h of pre-wetting, was 1,5 mm/h, with one-third of the test sites having nil infiltration and no site more than 5 mm/h infiltration. The durability of the carpark surface and turbidity of runoff were below expectations. This type of surface is not recommended.

In an effort to control pollution at source the 38-space carpark was designed to accommodate about half the number of cars as staff. Encouraging staff not to drive to work was supported by locating the building c. 900 m from a railway station and bus depot and setting up an internal website to assist with carpooling.

4.1.4 Design of the bioretention strip

The carpark drains to an adjoining bioretention strip that is 1,5 m wide and runs the length (30 m) of the main building. It exceeds sizing guidelines (USEPA 1999), being about 8% of the catchment's area. The bioretention strip is gently graded (1–3 %) and runoff is designed to pond in an extended detention depth of c. 50 mm.

A drainage trench 500 mm deep and wide runs the length of the bioretention strip and contains a 2:1 mix of coarse pumice sand and peat. The peat is intended to contribute adsorption sites for hydrocarbons, heavy metals, nutrients, and other contaminants (Robert Pitt, Univ. of Alabama, USA, pers. comm. 2005), but it may degrade quickly.

The trench is overlain with 200 mm of uncompacted Allophanic topsoil that provides a high surface area and friable structure. The topsoil also provides adsorption sites, but its key role is to store and supply water, nutrients, and air for plant growth.

Untreated *Cupressus macrocarpa* sleepers fastened 30 mm above the ground by chemset bolts replace the typical curb and channel. These inhibit soil compaction by traffic and encourage sheet flow delivery of water to reduce the likelihood of erosion.

About 50 mm of garden mulch was spread over the surface to protect it from erosion while the plants establish and prevent clogging of the surface by silt washed off the carpark. The mulch layer is expected to adsorb and filter pollutants and may provide an environment favourable to the growth of micro-organisms that degrade pollutants.

Native groundcovers were established that did not require mowing and would smother weeds and so minimise maintenance. The planting was designed to filter sediment from stormwater by imitating the favourable physical characteristics of a grass sward and included *Acaena microphylla*, *Fuchsia procumbens*, *Selliera radicans* and *Apodasmia similis*. A tussock edging reduces rain-splash onto the building and the dense *Scleranthus biformis* and *Selliera radicans* protect the soil surface from erosive drips falling from the building overhang. In our opinion the planting improves the site's visual landscaping.

4.1.5 Design of the raingarden

A raingarden with an 18-m^2 surface area flanks the main entrance to the building. It has a northerly aspect to maximise solar exposure and evapotranspiration. The key design features to improve stormwater treatment and retention include a deep (900 mm) multi-layered soil and delivery of water evenly across the upper surface.

A thick (300 mm) layer of topsoil with a high carbon content (>4%) and rapid permeability (>200 mm/h) was used to maximise the removal of metals from stormwater and ensure that anaerobic conditions did not develop in the topsoil. A moderately permeable subsoil was used to store moisture and adsorb contaminants. Based on moisture release data from intact cores, the raingarden is capable of storing about 5,5 m^3 of water within the profile, including 74 mm of readily plant-available water and 197 mm of total plant-available water.

The raingarden was planted with native plant species that have fine, dense and extensive root systems to maximise biofilms where biological activity is high. The *Muehlenbeckia astonii* and *Hebe speciosa* that were planted can tolerate annual clipping, which may be useful for harvesting bio-accumulated contaminants. Organic mulches were used to disperse the energy of stormwater, assist removal of contaminants, and suppress weeds until the native plants provide a dense cover.

4.2 Performance of the stormwater treatment train

Monitoring equipment was installed to measure water quantity and quality at the outflow of the bioretention strip and raingarden. Efficiency is described here as the ability to reduce runoff peak and volume, and the monitoring continues.

4.2.1 Stormwater treatment

A well-characterised event occurred on 24 January 2006, when 41,8 mm of rain fell in the 18 h between 3:09 a.m. and 5:45 p.m. (Figure 1). Initial low-intensity drizzle was followed by heavy showers in which rainfall intensity peaked at 2,3 mm/10 min, and 10,1 mm/h. The event was not unusual. The 2-year-return interval for the area is 70 mm in 24 h. Three weeks of predominantly dry conditions preceded the event, punctuated with only one small (<5 mm) rainfall event. With summer evapotranspiration rates of about 3 mm/d, it is expected that the stormwater devices had maximum water storage capacity available when rainfall began.

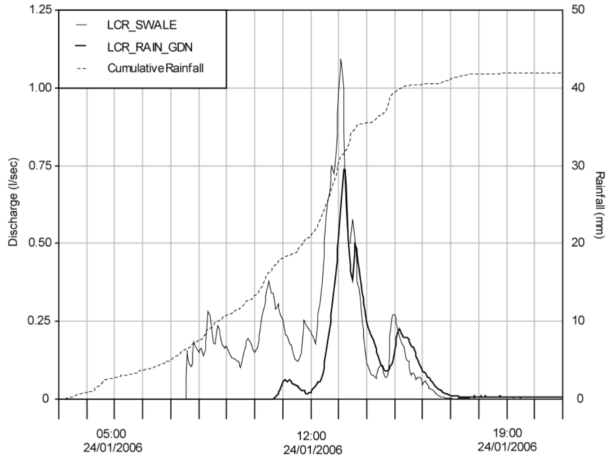

Figure 1 Hydrograph for the Landcare Research raingarden and bioretention strip.

Once depressions in the carpark surface were filled and rainfall intensity was greater than the infiltration rate, it is likely that much of the rainfall onto the carpark became runoff. This runoff was stored in the mulch and soil of the bioretention strip until 4,5 h and 7 mm of rainfall later, when the bioretention strip started to discharge into the raingarden. A further 3 h passed before the raingarden started to discharge. Up to this point 2216 L of stormwater had entered the raingarden. The total volume of water that fell on the catchment in the event was 31 800 L. The total discharge from the bioretention was 7889 L and from the raingarden 3031 L, meaning that <10% of the water that fell on the catchment discharged to stormwater pipes. The peak flow was also attenuated. The peak measured in the bioretention device was 1,09 L/s but was only 0,74 L/s in the raingarden.

4.2.2 Making a difference that counts

Landcare Research lodged a successful regional application (Moore and Morgan 2003) to support a number of stormwater initiatives in the catchment. The result was catchment-wide low-impact developments that include swales, raingardens, stormwater harvesting, and narrow roads that together increase the chance of real improvements to flow and water quality in the local stream.

5 WASTE WATER

One of the building design goals was to minimise discharge to the city's sewer and waste water system. The key to achieving this goal was the use of composting toilets.

5.1.1 Conventional toilet system

The dual-flush toilets and the urinals are connected to the city sewer system.

5.1.2 Grey water

Grey water from the laboratories, hand basins, glasshouses and kitchen drains to the sewer via a local sediment trap and a 1000-L detention tank. The tank can be used to isolate the drain if necessary, for example if there is a spill in a laboratory sink.

5.1.3 Composting toilet system

The composting toilet bins are connected to the city sewer to allow liquid that has not evaporated to drain. The bins are situated behind a glass window on the north wall and adjacent to the main entrance, so that the sun can heat them and assist the compost process, but also so that they are highly visible. The tank area has external access to make servicing easier when it comes time to use the compost product.

5.1.4 Aerating the compost

A bulking agent was added to the compost to increase the pore space and provide structure, allowing air to reach into the biomass and heat, water vapour and gas to be exhausted. It also helped approach the desired C:N ratio. Many of the bulking agents available to us were contaminated as they had been previously mixed with other waste materials. After some investigation uncontaminated wood shavings were sourced from a local furniture manufacturer, creating a small market for an otherwise waste material. The shavings had a C:N ratio of 420 and pH of 5.8.

5.1.5 Analysis of compost

Samples of about 1 L of compost were taken manually from the two compost bins (male and female) on 9 February 2006. Analyses were performed according to the *NZ Standard for Composts, Soil Conditioners and Mulches* (NZS4454, 2005). To provide context analyses were also performed on three, shop-bought composts: "Living Earth (A); Oderings Potting Mix (B); Results (C)". The results (Table 1) should be used as an indication only because of the inherent variability of composts. The NZ Standard values are for composts where a contribution to plant nutrition is claimed.

5.1.6 Composition of the compost

The Landcare Research composts compare favourably with the three commercially produced composts, although they require drying for efficient handling and transport. Moderate water-extractable nitrate, ammonium and phosphate concentrations and C:N ratios indicate both composts are likely to enhance plant growth.

Compost from the male unit had a higher C:N ratio than that of the female, because urinals bypass the compost resulting in a lower N content. The NZ Standard for composts suggests an optimum C:N ratio of 22:1 and the toilet manufacturer 20–30:1 (Clivus Multrum 2001). The ratio would be achieved by mixing the two composts.

Analyte	♂Compost	♀Compost	Commercial compost			NZS 4454
			A	B	C	
Total C (%) #	46.7	47.0	18.7	44.0	36.6	>15
Total N (%) #	1.88	2.57	1.58	0.83	1.14	>0.6
C/N ratio	25	18	12	53	32	>15
pH	6.6	6.1	7.9	4.7	7.1	n.s.
Nitrate-N §	104	228	116	241	0.3	n.s.
Ammonium-N §	130	134	0.8	6.4	0.3	n.s.
Reactive P §	234	171	7.7	24.3	7.0	n.s.
Dry bulk density ⬩	0.12	0.13	0.38	0.30	0.24	n.s.
Water content*	282	371	106	113	150	n.s.

Table 2 Analyses of toilet-derived and three commercial composts

(% = g per 100); § (measured in mg l^{-1}), ⬩ (measured in T m^{-3}), * (measured as % dry weight), n.s. = no sample.

In line with the principles of sustainability the composting toilets promote the use of a product that is typically considered a waste and in New Zealand the composting toilets better embody the traditional view of the indigenous Maori, who regard land-based disposal of human excrement and urea more appropriate than disposal to waterways (Waitangi Tribunal 1989; Durie 1994).

CONCLUSION

The Landcare Research building has provided a successful demonstration of what can be achieved to address the urban water balance. Despite research activities requiring the use of large volumes of mains water, the building still shows savings in the demands it makes on water resources and the wastes it emits to the environment. This was largely achieved by using composting toilets, rainwater harvesting and stormwater treatment devices. Monitoring is ongoing to better understand and fine-tune the systems and provide an integrated-urban-water-cycle benchmark performance measure for commercial buildings.

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