WATER BALANCE OF A GREEN BUILDING

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ABSTRACT

Monitoring results are presented as an annual water balance from the pioneering Landcare Research green building containing commercial laboratory and office space. The building makes use of harvested roof runoff to flush toilets and urinals and irrigate glasshouse experiments reducing the demand for city supplied water and stormwater runoff. Stormwater treatment devices also manage the runoff from the carpark helping curb stream degradation. Composting toilets and low-flow tap fittings further reduce the water demand. Despite research activities requiring the use of large volumes of water, the demand for city-supplied water is less than has been measured in many other green buildings. In line with the principles of sustainability, the composting toilets produce a useable product from wastes and internalise the wastewater treatment process.

KEYWORDS:

Green Building; Rain Tank; Compost Toilet; Stormwater Treatment, Tamaki Building.

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 its Auckland office to a 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 pioneering Landcare Research Tamaki Building won the Energy Efficiency and Conservation Authority's Energy-Wise Commercial Building award in May 2005 and it also received an "environmental hero" Green Ribbon Award from the Minister for the Environment. The building was designed to be energy efficient and make use of renewable materials and finishes that had a 100-year life.

The building's design also considered four urban waters: mains-, storm-, waste- and natural-. To minimise its impact on natural waters, it was designed to minimise demand for mains water and discharges of stormwater and sewage. This paper presents the measured operational performance of the building's water systems as an annual water balance (Figure 1) to show what has been achieved and to enable comparison of its performance with national and international practice. Context is provided by estimating the water balance of a similar building constructed using more conventional systems (Figure 2). The size of flow in the conventional water balance was estimated using the measured flow in the Landcare Research building. The annual period considered is the year ending 25 July 2007. The paper is structured around the building's *inputs* of water, *demands* for water and *outputs* of water.

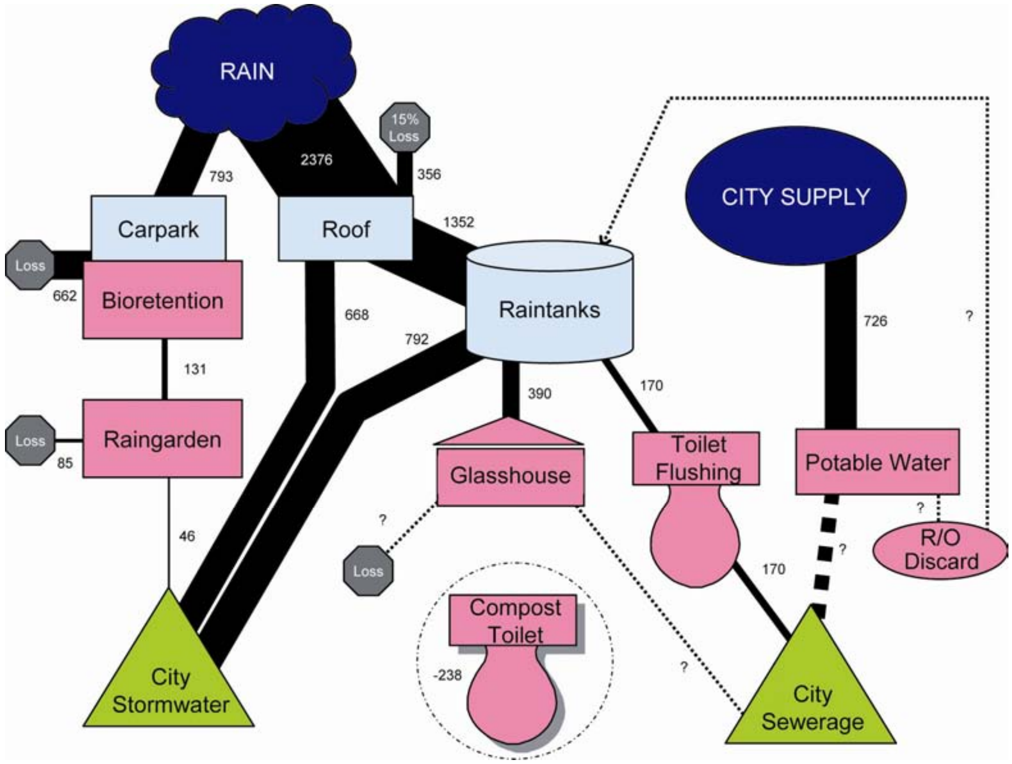

Figure 1 Water balance of the Landcare Research Tamaki Building. The thickness of the lines is proportional to the magnitude of flows, which are labelled and have the units m^3/ year ending 25 July 2007.

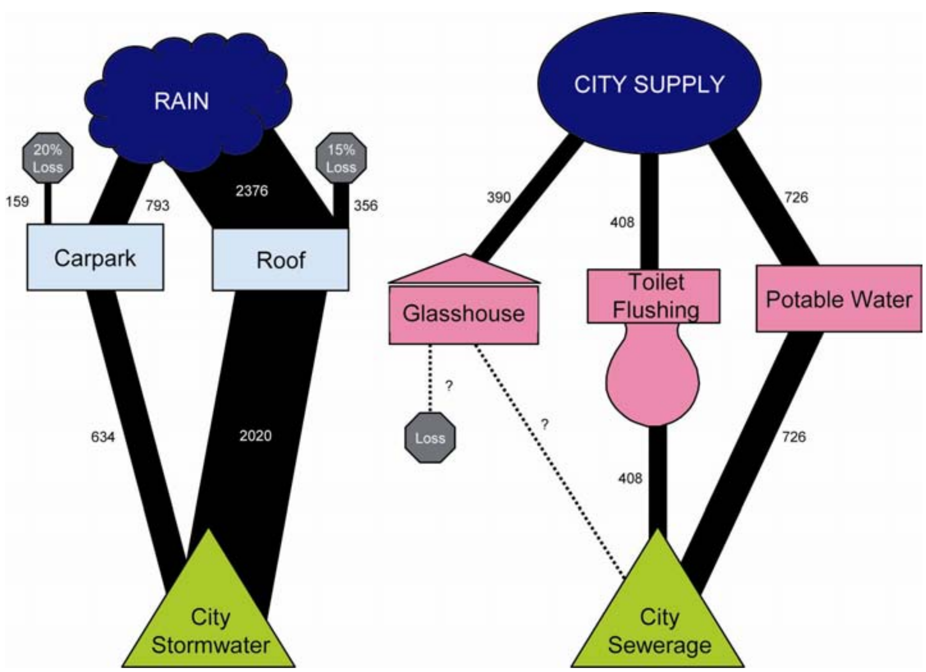

Figure 2 Water balance of a building similar to the Landcare Research building but using a more conventional system. The thickness of the lines is proportional to the magnitude of flows, which are labelled and have the units m^3/ year ending 25 July 2007.

INPUTS OF WATER

The inputs of water to the building include rainfall, harvested rainfall, and potable water supplied by the city's water main. The input size and method of measurement are presented before discussing their implications.

Rainfall

Rainfall is measured onsite using two (primary and backup), 0.2-mm tipping-bucket gauges. Data records are complete from 19 January 2005 to date. These data are further supported by climatic data collected at a weather station just 500 m from the building since December 1992. Auckland 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 total annual rainfall for the year ending 25 July 2007 was 1042 mm, similar to the long-term average rainfall of 1200 mm/ year (ARC 1999).

Water supply

The building is connected to the mains water supply. In addition, runoff from 1512 m^2 of 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. Water is pumped from these tanks to header tanks for use in the building. The third tank collects overflow. A mains backup is available for prolonged dry spells and for fire fighting. The volume of water running off the roof and into the tanks was 1352 m^3 in the period considered, assuming a 15% loss due to evaporation and storage on the roof. None of this water would be available for use if a conventional system had been used (Figure 2).

DEMAND FOR WATER

The core business operations of Landcare Research require laboratories and glasshouses that use a large volume of water. Rainwater harvesting, low-flow fittings and composting toilets reduce the water demand of the building (Figure 1 and 2).

Mains water

The building's potable water is supplied by the city mains supply. The local interpretation of the building code requires that hand basins, showers and kitchen appliances also be supplied by mains water. Low-flow fixtures and low-volume domestic appliances were used throughout. The building also draws on the city water supply to make 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. The volume of reject water has not been measured.

The consumption of city mains water has been measured hourly by the building management system since May 2006. A total of 726 m^3 was used during the year ending 25 June 2007. No mains water was used to top up rainwater tanks. The number of full-time-equivalent (FTE) employees was 94 making the total mains water used 7.7 m^3/ FTE/ year. Normalising for floor area (4828 m^2), results in a mains water use of 0.150 m^3/ m^2/ year.

The well known green building rating systems LEED (US Green Building Council, 2007) and NABERS (Department of Environment and Climate Change [New South Wales], 2007) provide sections on water. This has led to a number of green buildings reporting measured water use (NABERS) or being the target of post-occupancy evaluation based on promises made in the design stage (Turner, 2006). These data are used to provide context to the measurements made by Landcare Research.

Turner (2006) collated actual measured water use in US buildings that have attained a LEED building rating (Table 1). For comparison, measurements have been converted from imperial to SI. Turner's method assumed 365 days per year based on the reported employee counts for the King Street Center building.

Table 1 Actual water use measured in green buildings (after Turner, 2006)

	LEED rating	m^3/ FTE/ year	m^3/ m^2
Landcare Research building, NZ	N/A	7.7	0.150
Viridian Place, Portland, USA (commercial office)	Certified	7.8	0.179
Anonymous office building, NW region, USA	Certified	24.5	0.187
Balfour Guthrie office building, Portland, USA	Silver	8.4	0.244
Hillsdale Public Library, Portland, USA	Gold	7.8	0.321
Seattle Central Public Library, Seattle, USA	Silver	6.0	0.329
King Street Center, Seattle, USA	Gold	7.4	0.338

The Landcare Research building has comparable performance to these LEED-certified buildings. The water use measured in m^3/ FTE/ year was similar in most buildings, with the obvious exception of the anonymous office building. The Landcare Research building performed best using the metric m^3/ m^2.

A total of 59 buildings have achieved a NABERS score for water use but only one building scored a 5-star rating (0-0.35 m^3/ m^2/ year). That was the Szencorp building at 40 Albert Road, South Melbourne, Australia, which has been dubbed "Australia's greenest building" (Szencorp, 2006) and has also achieved 5-star Australian Building Greenhouse Rating (Department of Environment and Climate Change [New South Wales], 2007) and 6-star Green Star (Green Building Council of Australia, 2007). The Szencorp building's annual measured water use (0.131 m^3/ m^2/ year) was very similar to that measured in the Landcare Research Building (0.150 m^3/ m^2/ year). Interestingly, the measured water use in the second highest NABERS-scoring building was much higher at 0.391 m^3/ m^2/ year, which rated it a 4-star (0.35-0.7 m^3/ m^2/ year) building.

The data show that the Landcare Research building is one of the best-performing green buildings in terms of mains water use, and that is despite the large water demand for laboratories and glasshouses. The key to achieving this performance was the use of composting toilets and rainwater harvesting, which are discussed in the following sections. Interestingly the volume of harvested rainfall was greater than the building's total water demand, meaning that there is the potential to perform better.

Harvested rainwater

Harvested rainwater is used to flush dual-flush toilets and urinals. It is also used to irrigate the glasshouse experiments. The building management system records hourly demand for stored rainwater for toilets and glasshouses independently. A total of 170 m^3 harvested water was used to flush toilets during the year ending 25 July 2007. The glasshouses were a large user of water, requiring 390 m^3.

There are five dual-flush toilets on the ground floor and manual-flush urinals in the male facilities on all three floors. There are four manual-flush urinals in total. Composting toilets were not practical on the ground floor because the building is situated on basalt rock, making excavation for the bins very expensive.

Composting toilets were installed on the first and second floors of the building, where seven individual toilet pedestals are connected to two Clivus Multrum (2001) composting bins. The bins are gravity-fed from the male and female toilets and use no water for flushing. Assuming a similar water use per toilet as the building's dual-flush toilets, the compost toilets reduced water demand by 238 m^3 in the period considered.

Cost savings by reusing rainwater

Landcare Research was charged NZ$4.76 per cubic metre of water that it drew from the city water main. Landcare Research paid NZ$3,456 for mains water supplied for the year in question. The reuse of rain water saved NZ$2,666. Clearly, cost savings would have been larger if the building had been fitted with more-conventional toilets and appliances. The maximum potential savings can be described as the total value of all harvested water in the year ending 25 July 2007 (1352 m^3). At city supply prices, this gives a total potential cost saving of NZ$6,436 per year.

OUTPUTS OF WATER

Traditional methods to manage urban stormwater and wastewater have been shown to cause environmental degradation, which has driven the development of more sustainable management techniques (Wong, 2007). Some of these techniques are used in the building and are described here.

Stormwater

Two-thirds of the roof area (1526 m^2) drains to rainwater tanks, which help to reduce the stormwater volume and peak discharge to the city infrastructure. The remaining third (754 m^2), mainly that on the research glasshouses, drains directly to the stormwater network. Of the water collected in the tanks, 560 m^3 was used in the building while 792 m^3 went into storage. Some of that storage was 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 was slowly drained to the city stormwater network. The total volume of water used for irrigation or drained was very similar to the amount drawn from the city supply; 726 m^3, meaning that the Landcare Research Building has the potential to be self sufficient in water.

A series of stormwater treatment devices manage the stormwater from the building's carpark. The building's 761-m^2 carpark was designed with a permeable surface as the first step in stormwater treatment. Constructed of compacted gravels, the surface 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 having 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 and on 13 July 2007 the surface was tarmac-sealed.

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. 800 m from a railway station and bus depot, providing cyclist facilities (covered storage and showers), and setting up an internal website to assist with carpooling.

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 stormwater devices are described.

The bioretention strip is 1.5 m wide and runs the length (30 m) of the main building. It meets sizing guidelines (USEPA, 1999), being about 8% of the catchment area. The strip is gently graded (1-3%) and runoff is designed to pond to an extended detention depth of c. 50 mm. The bioretention was planted with native groundcovers that do not require mowing and that will smother weeds to minimise maintenance. The planting was designed to filter sediment from stormwater by imitating the favourable physical characteristics of a grass sward. The plants 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's overhang. In our opinion, the planting improves the site's visual landscaping. Untreated *Cupressus macrocarpa* sleepers fastened 30 mm above the ground by chemset bolts replace the typical curb-and-channel drainage system. These inhibit soil compaction by vehicles and encourage sheet flow delivery of water to reduce the likelihood of erosion and scour of the soils. Measurements show that during the study period, the bioretention discharged a total of 131 m^3 of water to the raingarden.

The raingarden has 18 m^2 of surface area and flanks the main entrance to the building. The northerly aspect maximises 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. The raingarden was also planted with native plant species, which were chosen for their fine, dense and extensive root systems to maximise biofilms where biological activity is high. The *Muehlenbeckia astonii* and *Hebe speciosa* 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. Just 46 m^3 of water was discharged from the raingarden to off-site treatment via the city stormwater network.

The annual water balance for the conventional building assumes a similar sized carpark that is tar-sealed and connected directly to the city stormwater network. A loss of 20% is assumed due to evaporation and storage on the carpark surface. In this case, the total annual volume discharging to the stormwater network was 634 m^3/ year, which is 1320% more than was measured when the treatment train was used. The estimate could be conservative given that the carpark is undersized for the building.

Figure 3 shows a well-characterised event that 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. 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 large but 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.

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 for 4.5 h, during which time 7 mm of rain fell, before the bioretention started to discharge to the raingarden. A further 3 h passed, during which 2216 L of stormwater entered the raingarden, before the raingarden started to discharge. The total volume of water that fell on the catchment in the event was 31 800 L. The total discharge from the bioretention was 7889L 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 flow measured exiting the bioretention device was 1.09 L/s and only 0.74 L/s from the raingarden.

The conventional system had a markedly different hydrograph (black line on Figure 3). The peak flow was nearly three times greater at 2.8 L/s, there was little lag time between rainfall and runoff, and the total volume discharged was much larger (23 400 L). There is a well-documented decline in habitat and water quality of urban streams (e.g. Paul and Meyer, 2001) due to increased runoff from directly connected impervious surfaces, such as roofs and roads, hydraulically efficient drainage systems, compaction of soils, and modifications to the vegetation. This can result in increased flood flows (Leopold, 1968), stream erosion (Hammer, 1972), and decreased baseflow through decreased groundwater recharge (Schueler, 1994). The effects of the building's stormwater treatment devices are masked at the stream habitat scale by the numerous other urban stormwater inputs to the stream, but presumably if we all treated our stormwater we would limit the degradation of stream habitat.

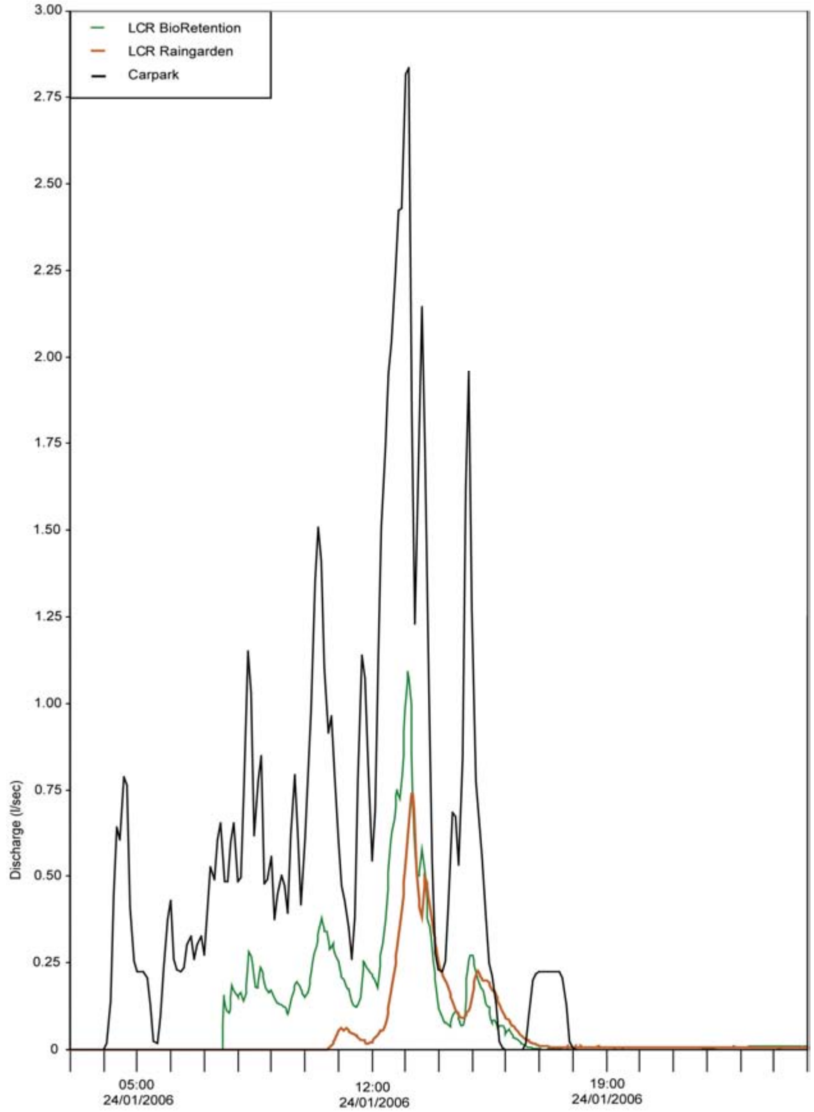

Figure 3 Hydrograph of discharge from the bioretention and raingarden at the Landcare Research Tamaki Building (brown and green lines respectively) and modelled discharge from a tarmac-sealed carpark (black line).

Wastewater

The dual-flush toilets and the urinals are connected to the city sewer system. The volume of water flowing from the flush toilets to the sewer was assumed to be similar to the volume used to flush the toilets (170 m^3). 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. Landcare Research is charged to dispose of every unit of water supplied by the city, so the discharge of potable water was assumed to be the same as supply (726 m^3).

The key to minimising discharges to the city's sewer and wastewater system was the use of composting toilets. The composting bins are connected to the city sewer to allow liquid that has not evaporated to drain, but most of the inputs are managed within. In line with the principles of sustainability the composting toilets promote the use of a product typically considered waste. The composting toilets also 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 (Durie, 1994).

The compost product has been shown to compare favourably to NZ Standards (NZS 4454) and commercially available composts where contribution to plant nutrition is claimed (Trowsdale et al., 2006), but the compost has yet to be used on site because of concerns about its safety. This is due in part to a lack of policy regarding appropriate handling and use of the material. While composting toilet systems have been used at the domestic scale (e.g. Vale and Vale, 2000), they are very rare in commercial-use buildings and to our knowledge these are the first compost toilets to be installed in a commercial-use building in New Zealand. Staff satisfaction of the composting toilets has increased during their 3-year operation and, in June 2007, 78% of staff said that they were completely or beyond-satisfied with using the composting toilets. This was the third highest ranked response in the building satisfaction survey.

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 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 data against which to benchmark building performance.

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