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Pilot Rainwater Harvesting Study Ireland

Liam McCarton
Technological University Dublin, liam.mccarton@tudublin.ie

Sean O'hOgain
Technological University Dublin, Sean.Ohogain@tudublin.ie

Anna Reid
Technological University Dublin, anna.reid@tudublin.ie

See next page for additional authors

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Authors
Liam McCarton, Sean O'hOgain, Anna Reid, Niamh McIntyre, and Jenny Pender

Pilot Rainwater Harvesting Study, Ireland

L. McCarton*, S. Ohogain*, A. Reid* and N. McIntyre**, J. Pender**

** Development Technology Centre, Department of Civil & Structural Engineering, Dublin Institute of Technology, Bolton Street, Dublin 1, Ireland (E-mail: liam.mccarton@dit.ie ; sean.ohogain@dit.ie; anna.reid@dit.ie)*
*** City Analysts Limited, Pigeon House Road, Ringsend, Dublin 4, Ireland*

ABSTRACT
There are no National Water Quality Standards for Rainwater Harvesting supply in Ireland. The Development Technology Centre (DTC) at the Dublin Institute of Technology was commissioned by the National Rural Water Monitoring Committee in 2005 to assess the feasibility of using rainwater harvesting to supplement treated mains water for non-potable uses. The project involved the design, installation, commissioning and monitoring of rainwater harvesting facilities for rural domestic and agricultural water supply. This paper will present the results from the domestic pilot rwh project. A dual water supply system was designed and installed to use rainwater collected from the roof surface to supplement mains water supply for toilet flushing and out door uses. A series of flow meters and a data logger system were installed to monitor micro component household water usage. Over the 19 month monitoring period, rainwater harvesting resulted in a saving of 20% of the total mains water supplied to the house. Harvested rainwater was tested monthly for physico-chemical and microbiological parameters. All samples complied with EU bathing Water Regulations. Compliance with the more stringent Drinking Water Regulations was achieved for ten of the nineteen sampling dates. Laboratory experiments were conducted using a variety of water related bacteria to determine time required to reduce a bacterial population by 90% at a given temperature. The laboratory experiments showed that hot water systems maintained at adequately high temperatures (60 ^{0}C) for 5 minutes effectively reduced the bacterial load from E.coli, Enterococcus faecalis, Pseudomonas sp and Salmonella to zero.

KEYWORDS
Demand management; health; hotwater systems; rainwater.

INTRODUCTION
The rapid economic growth in Ireland during the last ten years has resulted in increased water demand from both the industrial and domestic sectors. Demand is typically met by importing large volumes of water, treated to potable standards, from neighbouring catchments. Less than 1% of urban water consumption in Ireland is used for drinking (O'Sullivan, 2002). The temperate climate ensures consistent rainfall throughout the year. Average annual rainfall varies from 800 mm/yr for the eastern part of the island to 1250 mm/yr for the western region (Met Eireann, 2009). In many mountainous districts rainfall exceeds 2000 mm per year. Many households in rural Ireland do not have access to a local authority mains water scheme. Water supply to this sector is managed by Group Water Schemes. These comprise of private and part-private schemes, charged with sourcing and distributing potable water. This sector accounts for water provision to 29% of all rural households in the Republic of Ireland (EPA, 2006). The National Federation of Group Water Schemes (NFGWS) is the representative organisation for this sector in Ireland. There are no National Water Quality Standards for Rainwater Harvesting supply in Ireland. Health concerns over bacterial contamination of rainwater supply have limited the development of a national strategy.

This study was ccommissioned by the National Rural Water Monitoring Committee in 2005, to establish scientific data that will facilitate reasoned debate and contribute towards the development of a national strategy to integrate rainwater harvesting for non-potable uses. The project involved the design, installation and commissioning of a domestic and agricultural rainwater harvesting system. This paper will discuss the results from the domestic pilot.

METHODOLOGY

Site Location

The site for the domestic use of rainwater was a new housing estate situated in a rural catchment in the South East of Ireland. The development is supplied by mains water via a group water scheme. Rainwater harvesting (rwh) facilities were installed on selected houses with flow monitors on adjacent houses acting as baseline controls.

Rainwater Harvesting Installation

Figure 1 shows the components of the rwh system installed. The roof was of vitrified clay tiles with a catchment area of $75m^2$. Rain was collected by 80mm plastic gutters and flowed via the downpipes through an inline underground filter and calming inlet to the underground collection tank. This was a $9m^3$ precast concrete tank. A submersible pump controlled by the supply management system pumped rainwater to an internal rainwater header tank. Internal plumbing was modified to provide a direct gravity feed from the rainwater header tank to toilets. During periods of dry weather, if there was insufficient water available in the rainwater header tank a mains top up device was activated via a solenoid valve. To prevent cross-contamination between the rainwater and the mains supply a 40 mm air gap and tundish was fitted to the mains water top up system.

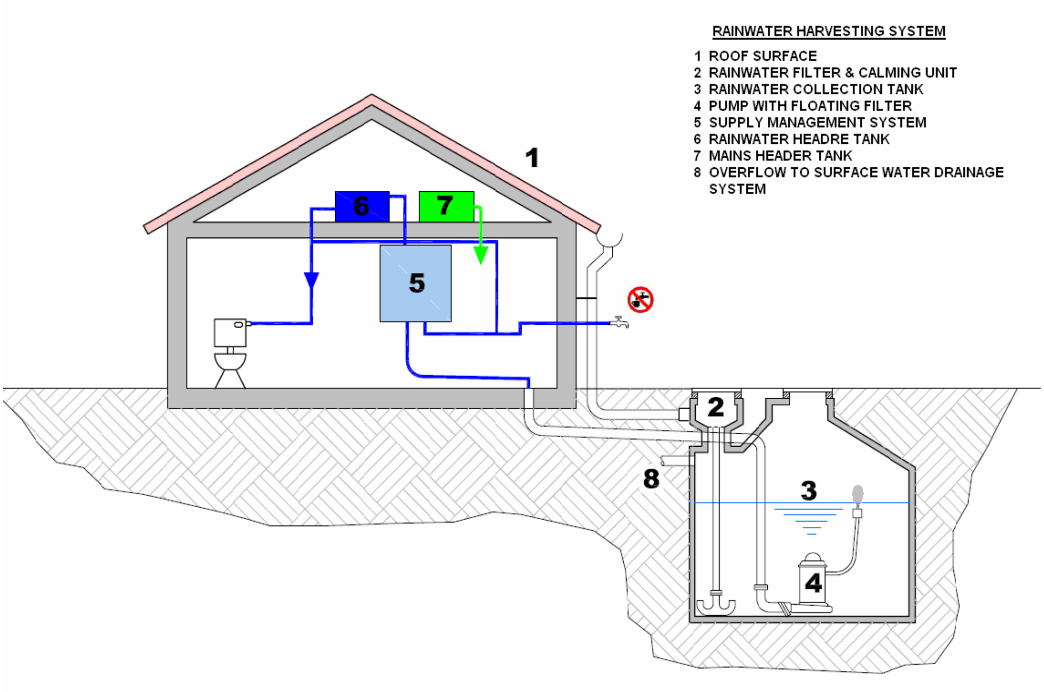

Figure 1 Schematic of rainwater harvesting system

Flow Monitoring

A data logger system with flow monitoring was used to assess micro component household water usage. A remote monitoring system using mobile phone technology was used to collect flow data. A weather station was installed to generate water balance data for the site.

Rainwater Quality

Rainwater from the underground reservoir was sampled monthly for nineteen months between January 2006 and July 2007. The physico-chemical analysis tested for Chloride, Nitrate, Nitrite, Sulphate, Ammonia, pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Turbidity, Sodium, Calcium, Lead, Iron and Cadmium. Samples for microbiological analysis were taken in sterile bottles to ensure no cross-contamination. They were analysed for the time dependent parameters Coliforms, *E. coli*, Faecal coliforms, Total Viable Counts (TVC) at 22ºC and 37ºC and Pseudomonas spp. within1 hour of receipt in the laboratory. All analysis of water quality parameters was carried in an Irish National Accreditation Body (INAB) accredited laboratory. In order for water to be considered fully potable it must undergo testing for 28 different parameters set out in the full audit monitoring list of the European Communities Drinking Water Regulations (S.I. No. 278, 2007). One full audit suite of testing was carried out on the rainwater supply.

Thermal Destruction Experiments

Health concerns over bacterial contamination of hot water systems have hindered the use of rainwater in hot water systems. This pilot study addressed the existing lack of research on the thermal inactivation rates of micro-organisms. A series of tests were conducted in a controlled laboratory setting to examine the thermal destruction behaviour of pathogens at a range temperatures likely to occur in a domestic hotwater system. The bacterial species used in these experiments included, *E.coli*, Enterococcus faecalis, Pseudomonas sp and Salmonella, which were obtained from the Health Protection Agency in Newcastle, England. Lenticules of known values were stored at -4ºC prior to re-constitution in a sterile phosphate buffer solution. 500ml sterile water samples were spiked with known concentrations of each bacterial species. They were then placed in a heated water bath of 55ºC and 60ºC respectively. A calibrated temperature probe was placed in a control sample of water and this was also placed in the water bath. This recorded the temperatures at given intervals of 5, 10, 15 and 20 minutes. The first aliquoted sample was analysed at Time 0. This was prior to sample incubation in the water bath. Once the desired temperature of 55 and 60ºC respectively were reached, a timer was set for each of the 5 minute intervals. Sample aliquots were then taken and analysed for each of the above.

RESULTS AND DISCUSSION

Harvested rainwater supply versus demand results

Total mains water useage for the rwh house and 3 control houses over the 19 month period was 87m^3, 430m^3, 173m^3 and 503m^3 respectively. This corresponds to a per capita consumption rate (pcc) of 77 l/hd/d, 125 l/hd.d, 84 l//hd/d and 157 l/hd/d respectively. Average pcc rates for this district from a review carried out in 1997 was 132l/hd/d (Atkins, 2001). Changing demographics in Ireland indicate reduced number of occupants with households located farther from work with resulting less time spent at home. This could partly account for the lower pcc rate in the study population. Toilet flushing in the four houses accounted for between 22–41% of total water use with a total of 20m^3 supplied by harvested rainwater for the study period Hot water systems accounted for between 13% to 37% of total household water use.

Discussion of results

The RWH system was designed for water use of 45 l/hd/d in a 4 person household with 30 days dry storage period, resulting in a 9m^3 storage tank. Figure 2 shows the flow monitoring results for monthly harvested rainfall versus demand during the monitoring period January to December 2007. Rainwater only supplied toilet use in the study household. It can be seen that supply significantly exceeds demand resulting in frequent overflow of the system. Figure 2 illustrates how the RWH system would cope with an additional demand of supplying the hot water needs for the household.

This study indicates that the rwh system could potentially meet the household’s toilet and hot water demand.

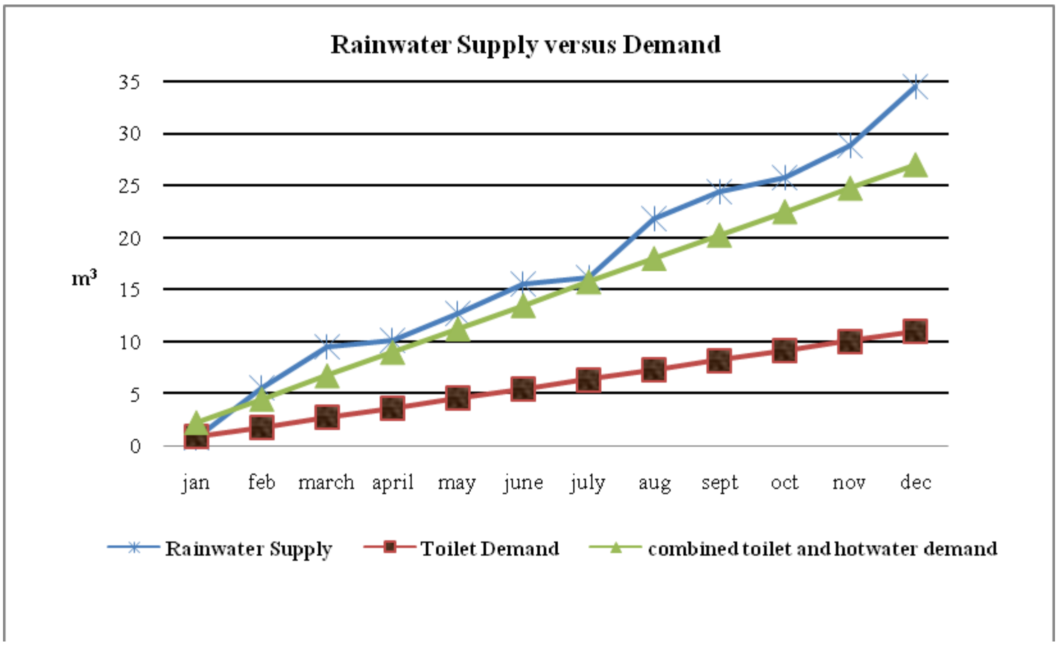

Figure 2. Rainwater Supply versus Demand for Study Household

Physico chemical harvested rainwater quality results

It was considered an important function of the project to collect water quality data for untreated harvested rainwater. No disinfection programme was carried out at any stage in the rainwater harvesting process. No first flush device was fitted to the system. The physico-chemical results for the domestic site are shown in Table 1. There are currently no specific national guidelines applying to the use of rainwater for domestic non-potable supply. Results for the harvested rainwater quality are compared with the European Communities Drinking Water Regulations (S.I. No. 278 of 2007) and the European Communities Quality of Bathing Water Regulations, (S.I. 155 of 1992) (henceforth referred to as EU Drinking Water Regulations and EU Bathing Water Regulations respectively). The physico-chemical quality of harvested rainwater in Carlow showed 100% compliance with the EU Bathing Water Regulations. Compliance with the more stringent EU Drinking Water Regulations was achieved for all parameters except pH and Lead (Pb).

Discussion of results

The EU Drinking Water Regulations impose a parametric value of 25 µg/l Pb until the 25th December 2013 after which the parametric value of 10 µg/l Pb becomes effective (EPA, 2006). The harvested rainwater was in breach of the 10 ug/l limit on 5 occasions with the highest level being over twice the maximum allowed at 25.32 mg/l. This represented a 73.6% compliance rate. Construction of phase two of the development was ongoing during the sampling period. This could have contributed to the presence of lead in the rainwater. However, a more likely contribution to the lead in the rainwater were the flashings used on the rainwater harvesting house. The soft nature of the rainwater may have leached some lead from these flashings

Table 1. Physico-chemical results for harvested rainwater based on 19 monthly samples during monitoring period Jan 2006 to July 2007

Parameter	Units	Mean	Min	Max	Median	EU Drinking water Regs.	EU Bathing Water Regs.
Chloride	mg/l	5.73	1.50	22.49	5.06	**250 mg/l**	
Nitrate as NO3	mg/l	1.14	0.00	2.84	1.24	**50 mg/l**	
Nitrite as NO2	mg/l	0.06	0.00	0.49	0.03	**0.50 mg/l**	
Sulphate	mg/l	8.66	0.00	31.70	7.50	**250 mg/l**	
Ammonia as NH3	mg/l	0.12	0.00	0.77	0.05	**0.28 mg/l**	
pH	pH	7.24	6.26	8.21	7.21	**6.5 - 9.5**	**6.0 - 9.0**
TDS	mg/l	84.63	6.00	189.00	77.00		
TSS	mg/l	5.37	0.00	25.00	4.00		
Turbidity	NTU	1.10	0.00	4.60	1.11	**NAC&ATC***	
Sodium	mg/l	4.15	0.00	8.60	4.60	**200 mg/l**	
Calcium	mg/l	13.32	3.10	23.20	14.00	**None**	
Lead,Total	µg/l	5.74	0.00	25.32	1.98	**10 µg/l****	
Iron,Total	µg/l	25.66	0.00	95.03	21.73	**200 µg/l**	
Cadmium,Total	µg/l	0.03	0.00	0.30	0.00	**5.0 µg/l**	

*No abnormal change and acceptable to consumers

**The regulations impose a parametric value of 25 µg/l Pb until 25 December 2013 after which the value will be 10 µg/l.

Micro biological water quality results

Table 2 presents the microbiological monitoring results for the domestic site over the 19 months of sampling between January 2006 and July 2007. Mean and maximum concentrations for coliforms, E.coli and Faecal coliforms are in breach of EU Drinking Water Regulations but are within acceptable limits set by the EU Bathing Water Regulations.

Table 2. Microbiological results for harvested rainwater based on 19 monthly samples taken during monitoring period Jan 2006 to July 2007

Analysis	Units	Mean	Min	Max	Median	EU Drinking Water Regs	EU Bathing Water Regs
Coliforms	MPN/100ml	217	0	1203	365	**0/100ml**	**5000/100ml**
E.coli	MPN/100ml	0.39	0	7.50	3.75	**0/100ml**	**1000/100ml**
Faecal Coliforms		3.00	0	22.00	0.00		**1000/100ml**
TVC @ 22ºC	Cfu/100ml	3264	1	35,400	546	**NAC***	
TVC @ 37 ºC	Cfu/100ml	216	3	704	169	**NAC***	
Pseudomonas spp	Cfu/100ml	6.00	0	80.00	15	**0/100ml**	

*No abnormal change

Table 3 presents a summary of the microbiological results after the first six months of operation. A pronounced improvement in harvested rainwater quality occurred after the first six months. No coliforms, *E. coli* or faecal coliforms were detected in any of these samples.

Table 3. Microbiological results for harvested rainwater after initial 6 month commissioning period, based on monthly samples taken during monitoring period June 2006 to July 2007

Analysis	Units	Mean	Min	Max	Median	EU Drinking Water Regs	EU Bathing Water Regs
Coliforms	MPN/100ml	0	0	0	0	**0/100ml**	**5000/100ml**
E.coli	MPN/100ml	0	0	0	0	**0/100ml**	**1000/100ml**
Faecal Coliforms		0	0	0	0.00		**1000/100ml**
TVC @ 22ºC	Cfu/100ml	975	1	3,000	300	**NAC***	
TVC @ 37 ºC	Cfu/100ml	242	3	704	183	**NAC***	
Pseudomonas spp	Cfu/100ml	7.92	0	80.00	0	**0/100ml**	

*No abnormal change

Discussion of results

In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with human or animal faeces. Faeces can be a source of pathogenic bacteria, viruses, protozoa and helminths. Faecally derived pathogens are the principal concerns in setting health-based targets for microbial safety (WHO, 2006). The microbiological results show compliance with EU Bathing Water Regulations at all times. Compliance with the more stringent Drinking Water Regulations was achieved on ten out of nineteen sampling dates. Three distinct trends show up within the results . The initial 6 month period from January 2006 to June 2007 showed levels of faecal indicator organisms (coliforms, *E. coli* and faecal coliforms) present, in breach of Drinking Water Regulations. A second trend appears from July 2006 to April 2007. During this period no faecal indicator organisms were detected and the harvested rainwater was in compliance with Drinking Water Regulations. This water was suitable for use as potable water during these 10 months. A further trend appears in the last three sampling dates, where the water quality shows breaches of the Drinking Water Regulations in relation to the Coliform parameter only. E coli was not detected during this period.

There are no limits for Total Viable Counts (TVCs) in EU Bathing Water Regulations. EU Drinking Water Regulations require that there are no abnormal changes in numbers detected when monitoring systems over a period of time. A sudden increase in the numbers of micro-organisms counted can mean that a pollution incident has occurred to upset the normal microbiological balance of the system. The results show that TVC counts from the rainwater harvesting system were extremely variable. This indicates that the system is not microbiologically stable. No chlorination of harvested rainwater was carried out at any stage during the project. As a result, there was no residual chlorine present to keep the water microbiologically stable.

Heat Treatment Experiments

The aim of the thermal experiments was to determine the time required to reduce a bacterial population by 100% or 1 log reduction, in a water medium at temperatures relevant for domestic hot water systems. Table 4 shows the microbiological results for Coliforms, *E. coli*, Faecal Coliforms, Salmonella, Pseudomonas aeruginosa and TVC (at 22ºC and 37ºC). Experiments were carried out at 55ºC and 60ºC respectively in order to investigate the correlation of reduction rate and temperature.

Table 4. Microbiological results for heat treatment experiments carried out at 55^0C and $60\ ^0C$

Parameters	Unit	Temp Deg C	0 mins	5 mins	10 mins	15 mins	20 mins
Coliforms	MPN/100ml	55	248.3	2.1	0	0	0
		60	261.3	0	0	0	0
E coli	MPN/100ml	55	248.3	2.1	0	0	0
		60	261.3	0	0	0	0
TVC @ 22^OC	Cfu/ml	55	88	0	0	0	0
		60	90	0	0	0	0
TVC @ 37^OC	Cfu/ml	55	88	0	0	0	0
		60	90	0	0	0	0
Pseudomonas spp	Cfu/100ml	55	12	0	0	0	0
		60	15	0	0	0	0
Faecal Coliforms	Cfu/100ml	55	36	0	0	0	0
		60	34	0	0	0	0

Discussion of results

The 55°C results show that reduction in bacterial load is not as rapid for Coliforms and *E. coli* as at 60°C. At 55°C it requires 10 minutes exposure to temperature to reduce the Coliforms and *E. coli* population to zero. The other bacterial populations are completely removed after 5 minutes at 55°C. The 60°C results show all parameters removed after 5 minutes contact with the water. This study indicates that hot water systems maintained at adequately high temperatures reduces the bacterial load to zero. The results of these laboratory experiments are in agreement with water samples taken from domestic rainwater tanks and hot water systems in Australia which indicated almost complete kill off of bacteria through the hot water system (Spinks et.al, 2003). These results have significant implications for rainwater harvesting use within domestic hot water systems. Hot water system temperatures are regulated in Ireland by the Chartered Institution of Building Services Engineers (CIBSE) Guidelines Guides B and G, and also by the CIBSE guidelines on Legionnaires disease. These standards state that the storage water temperature should not exceed 65°C. Bacterial populations in hot water systems maintained at 60°C will be reduced rapidly.

CONCLUSIONS

This study showed that harvested rainwater has the potential to supplement mains water supply for non potable use in Ireland. Over the 19 month monitoring period, rainwater harvesting resulted in savings of 20% of total mains water supply. The maximum monthly demand observed for toilet use was $1.1m^3$. Rainwater harvesting system design for toilet water use could use a significantly reduced storage tank size. This would increase efficiency in system performance and effect capital cost savings.

The physico chemical rainwater quality showed 100% compliance with the EU Bathing Water Regulations. Compliance with the EU Drinking Water Regulatiosn was achieved for all parameters except pH and Lead. The micro biological rainwater quality showed 100% compliance with the EU Bathing Wayer Regulations. Compliance with Drinking Water Regulations was achieved for 10 of the 19 sampling dates. The significantly improved water quality results from “real” rainwater tanks suggest that, at a minimum, rainwater tanks can supply water of acceptable quality for toilet flushing and outdoor use and via hot water systems for hot water use.

Laboratory experiments showed that enriched bacterial populations decreased rapidly with initial exposure to thermal stress. This study indicates that hot water systems maintained at adequately high temperatures reduces the bacterial load to zero. In view of Irish standards requiring temperature at or above 60°C to control *L. pneumophila*, these preliminary results suggest that it is highly improbable that human pathogens, if present in harvested rainwater water supply, will survive through a hot water system.

The centralised import-export approach has changed little over the last 120 years in Ireland. It is unsustainable to supply urban areas with water harvested from river systems whilst ignoring the resource potential of locally derived rainwater. For domestic water supply in Ireland, this study has shown that rainwater harvesting should be adopted by Local Authorities as part of an integrated water management strategy.

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