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Rainwater Harvesting Pilot Project Report

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Rainwater Harvesting
Pilot Project

This study and report were undertaken under the auspices of the National Rural Water Monitoring Committee by a project team from the School of Civil and Structural Engineering at Dublin Institute of Technology. The project team was led by Dr Seán Ó hÓgáin and Liam McCartan and included Anna Reid, Niamh McIntyre and Jenny Pender.
The project team gratefully acknowledges the co-operation of Ballinabrannagh Group Water Scheme and of Hugh Hayes of Clonalvy who provided the study sites.

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EXECUTIVE SUMMARY

Introduction

The rainwater harvesting pilot project was commissioned by the National Rural Water Monitoring Committee in 2005 to assess the feasibility of supplementing treated mains water used for non-potable purposes. The project involved the design, installation, commissioning and monitoring of rainwater harvesting facilities in a rural housing development in County Carlow and in a 250-acre livestock farm in County Meath. Construction was carried out between 2005-2007.

Domestic Site

The installation at four houses (one rainwater harvesting facility and three control houses), was commissioned in late 2005 and sampling began in January 2006.

The rainwater harvesting system collected water from roof surfaces only and was diverted through filters from the down-pipes to an underground tank. All connections to the rainwater drainage system were sealed to prevent contamination from surface water.

Harvested rainwater was pumped to a separate rainwater header tank located in the attic. This was then delivered by gravity to provide water for toilet flushing and external garden taps.

In periods of low rainfall, the rainwater header tank was filled from the mains water supply. Care was taken to ensure that no backflow to the mains supply could occur.

A data logger system monitored micro-component household water usage, while a weather station generated water balance data.

Results: Domestic Project

Harvested rainwater at the domestic installation complied with the Bathing Water Regulations in 100% of samples taken (and was of suitable quality for all non-potable applications), while 37% of samples complied with the more stringent Drinking Water Regulations.

An efficient disinfection programme would have ensured that the quality of the harvested rainwater was in compliance with the microbiological parameters for drinking water.

Exceedances in terms of the parameter for Lead suggests that lead flashings should never be used where rainwater is to be employed for potable applications.

Regular maintenance of the system is essential to ensure optimum water quality.

Monitoring of water demand and component usage showed that rainwater supply to toilets in a domestic situation has the potential to reduce daily mains water demand by up to 33%.

Agricultural Site

Comissioning of this system began in September 2005 and was fully operational by Spring 2006.

The farm buildings lay in the centre of the farm and included two sheds/barns, each of approximately 1,000m^2 roof area. Rainwater from the two sheds/barns was drained by gravity to an underground collection tank. The water was pumped to pre-cast concrete reservoir tanks located on an adjacent elevated site.

As in the domestic site, a mains top-up connection ensured a supply to the reservoir during periods of low rainfall.

Harvested rainwater was distributed by gravity to drinking troughs for cattle on the farm. A data logger system was installed with flow monitoring to assess water usage.

A weather station was installed on site to generate water balance data.

Initially, the installation was designed to test low-cost and low-tech filters that could be fabricated and maintained by an individual farmer. However, due to the unsatisfactory performance of this filtration system, it was decided to replace it.

Improved filters were installed on the three downpipes conducting the rainwater to the collection tank and also on the fine filter of the pump in the collection tank.

Armstrong Junctions (AJs) covering the underground pipework in the farmyard were sealed, to eliminate contamination from farmyard run-off.

Results: Agricultural Project

The use of non-proprietary filters and the ingress of contamination through faulty seals in the underground pipework resulted in a serious deterioration in the quality of the harvested rainwater for part of the study period. In terms of microbiological quality, samples breached both the Bathing Water and Drinking Water parameters, while ammonia exceedances were present in all tests conducted. With proper installation of proprietary filters, both microbiological and chemical quality greatly improved, but the Ammonia parameter, in particular, remained problematic.

Monitoring of water demand and water use on the farm showed that rainwater supply replaced 43% of the mains water used in the drinking troughs.

Conclusions

Amongst the conclusions drawn from both studies were the following:

1. Rainwater harvesting is a sustainable water conservation measure that has the potential to contribute to the sustainability of raw water sources and to the viability of water treatment plants.

2. Harvested rainwater has the potential to provide a supplementary source to treated mains water for non-potable uses. It may, under appropriate conditions, be used in domestic hot water systems.

3. In all situations the design and installation of a rainwater harvesting system should be undertaken by competent/specialist trained personnel and regular maintenance will be required to ensure optimum performance.

4. In the context of current water charging policies, there is little or no incentive to installing rainwater harvesting systems

5. A significant level of grant aid would be required to make it a viable option for consumers.

6. The potential benefits of rainwater harvesting are not widely appreciated and this should be addressed through an educational awareness programme.

7. The principal beneficiary of rainwater harvesting systems is the water supplier.

Recommendations

Arising from this study, the recommendations may be summarised as follows:

1. Rainwater harvesting systems merit positive consideration and the benefits should be promoted through an awareness/education programme including basic advice/tips for those considering the installation of such a system.

2. Those involved in building development projects (design and construction) should be actively encouraged to consider the use of a rainwater harvesting system from the outset.

3. Further exploratory work needs to be undertaken on the potential for harvested rainwater systems in non-domestic applications, including other farm types.

1: INTRODUCTION

1.1 SUSTAINABLE DEMAND MANAGEMENT: NEW IDEAS & APPROACHES

The rapid expansion of urban areas in Ireland in recent years, along with increased demand from both the industrial and domestic sectors, has placed a growing demand on water resources. This continued pace of socio-economic development is posing problems for water supply infrastructures never intended to service the levels of demand being experienced. Consequently, there is a countrywide need for investment in additional water supply infrastructure. Water demand resulting from urban development is typically met by importing large volumes of water across large distances – and at considerable cost – from neighbouring catchments. This water is then treated to drinking water quality standards. At the same time, similar volumes of storm water from roofs and allotments are discharged unused from urban developments via expensive storm water systems. Less than 1% of urban water consumption is used for drinking. However, all mains water supply is treated to potable quality [O'Sullivan, 2002].

New approaches and novel technical solutions for water management need to be developed and implemented. These new approaches must be based on resource conservation principles. Small-scale, low-cost technological solutions that are based on local traditions, are decentralised and are ecologically sound, warrant positive consideration.

One method of potentially reducing demand on treated water is the use of rainwater harvesting to augment supply. Given Irish rainfall levels, rainwater collected from domestic roofs and farm buildings for non-potable uses has the potential to replace a considerable portion of water consumption, significantly reducing the need to harvest and store a treated water supply, while also reducing storm water discharges to downstream environments.

1.2 SCOPE OF THE STUDY

Commissioned by the National Rural Water Monitoring Committee in 2005, this study was designed to assess the feasibility of rainwater harvesting systems replacing treated mains water for non-potable uses. The project involved the design, installation, commissioning and monitoring of rainwater harvesting facilities in a rural housing development and in a farm setting. The aims of the study were as follows:

- To develop a pilot project to assess the feasibility of incorporating rainwater harvesting from selected roof areas and utilising this supply to supplement/replace mains or other water supplies to reduce demand in rural group water supply schemes.
- To develop a pilot project on a farm, incorporating best practice in water efficiency measures and rainwater harvesting.
- To quantify the amount of harvestable rainwater in an Irish location.
- To quantify the water savings from rainwater harvesting and water efficiency measures.
- To calculate the reduction in per capita demand on treated mains water supplies.
- To monitor the quality and quantity of harvested rainwater over a 24-month period.

1.3 STUDY LOCATIONS

Two sites were identified; a housing development within Ballinabrannagh Group Water Scheme in County Carlow and a farm at Clonalvy County Meath.

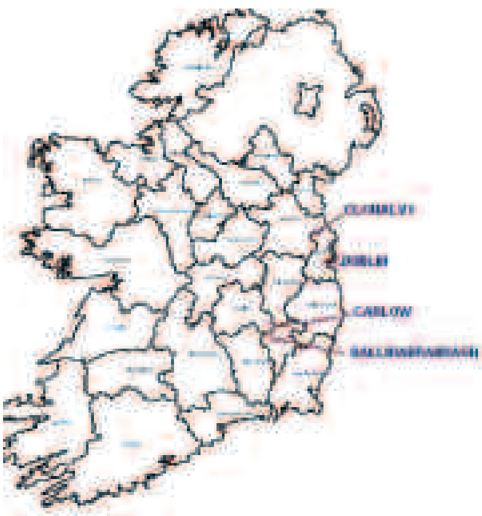


Fig 1.1 Locations of pilot rainwater harvesting sites.

PILOT SITE 1: Co. Carlow

- Domestic Dwelling
- Catchment Area 75m^2
- Rainwater Storage Tank 9m^3

PILOT SITE 2: Co. Meath

- 250 acre farm
- Catchment Area 1,910m^2
- Collection Tank 9m^3
- Rainwater Storage Tank 44m^3

2: DOMESTIC PILOT RAINWATER HARVESTING INSTALLATION

2.1 PILOT SITE 1: HOUSING DEVELOPMENT, BALLINABRANNAGH, COUNTY CARLOW

- House Type: Detached Timber Frame Single Storey Dwelling
- Roof Catchment Area: 75m^2
- Roof Type: Vitrified Clay Tiles
- Rainwater Storage Tank: Precast RC Tank , Capacity 9m^3
- Internal RWH Supply Tank: Precast Plastic 25 gallon tank pre-fitted with float switch and cable assembly unit
- Submersible pump
- A Rainman 1Tm in-line filter
- Control Panel
- Data logger system with flow monitoring to assess micro-component household water usage
- Weather station installed on site to generate water balance
- Phase 1 – 1 RWH House, 3 control houses with flow meters
- Phase 2 – 6 RWH houses, 5 control houses with flow meters

2.1.1 System Design

A dual water supply solution – using rainwater from a tank to supplement mains water supply for toilet flushing and outdoor uses – was proposed for the Carlow development. Standard rainwater system designs for domestic installations utilise either direct feed from the underground tank to the point of use (a pressurised system) or direct feed to a separate rainwater storage header tank located in the attic (gravity feed). The gravity system was specified. One of the principal design considerations was the provision of a back-up supply from the mains system to maintain water supply to the toilets during periods of low rainfall. Water authorities in Britain require the installation of an appropriate backflow prevention device, or method to prevent contamination of mains water by rainwater.

Two options were available in RWH systems:

- Trickle top-up of the underground rainwater tank with mains water to a minimum level when the rainwater tank water level falls below that level. In this system, a mechanical float system is used to control the trickle top-up and an air gap is employed for backflow prevention.
- Switch between mains and tank water supply using a solenoid valve and a water level sensor in the rainwater tank. When the rainwater tank is empty, mains water is used to supply all uses

It was decided to specify the top-up supply to the header tank in the attic using a solenoid valve for the domestic pilot installation and to utilise the trickle top-up on the agricultural installation in order to compare the performance of both systems.

2.1.2 Potential Rainwater Yield

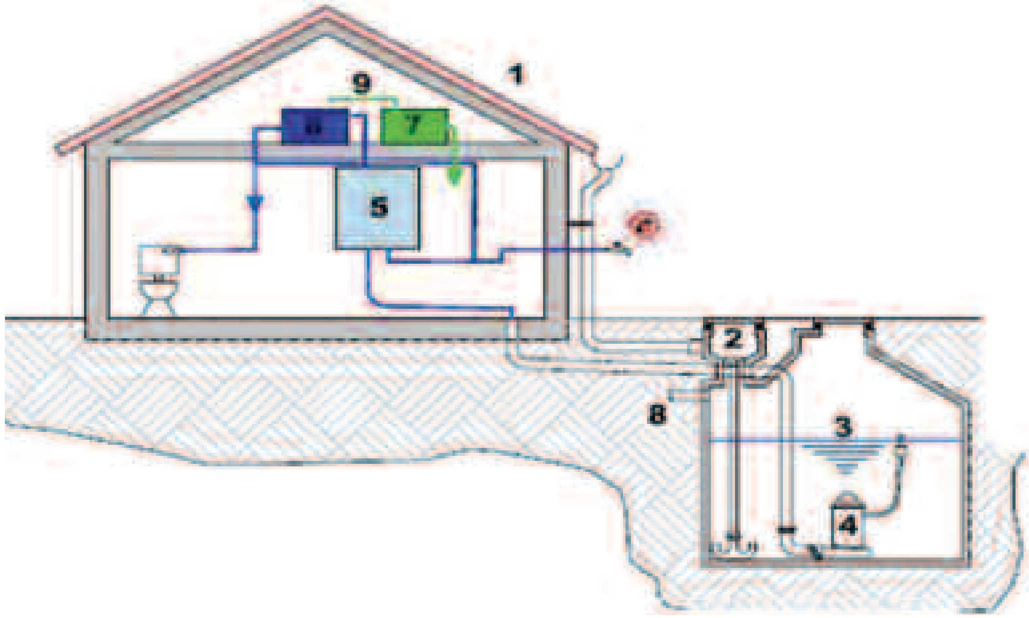
The potential yield from rainwater is a function of the roof size, roof type and filter efficiency. Table 2.1 shows the relationship between roof size and annual rainfall.

Plan Roof Area (m^2)		50	75	100	150	300	500	1,000
Annual Rainfall (mm)	750	25	38	51	76	152	253	506
	900	30	46	61	91	182	304	608
	1,000	34	51	68	101	203	338	675
	1,200	41	61	81	122	243	405	810
	1,400	47	71	95	142	284	473	945

Table 2.1 Potential annual yield of rainwater (m^3) for a range of roof sizes.

The underground storage tank was sized to balance potential yield and demand. A standard 9m^3 precast tank was specified in order to reduce delivery times and to minimise cost. The RWH system was designed for water use of 45 litres per head per day (l/hd/d) for toilet use in a 4-person household and 30 days dry storage period. Provision was also made in the sizing of the tank to provide rainwater supply to the hot water system.

Throughout the project, the harvested rainwater supplied toilet flushing only and thus the tank was oversized for the demand. A tank of 2-4m^3 would be sufficient to supply only toilet demand for rainwater supply.



Rainwater Harvesting System

1. **Roof surface**
2. **Rainwater filter**
3. **Rainwater storage tank**
4. **Pump**
5. **Supply management system**
6. **Rainwater header tank**
7. **Mains water header tank**
8. **Overflow to surface water drainage system**
9. **Mains water top-up**

Fig. 2.1 Schematic of rainwater harvesting system installed in Carlow.

Figure 2.1 shows the components of the RWH system installed. The house roof is the catchment area (1), rain is collected by the gutters and flows through the downpipes through a filter and calming inlet (2) to the underground collection tank (3). A submersible pump (4) controlled by the supply management system (5) pumps rainwater on demand to the rainwater header tank (6) for supply to the household toilets and garden tap. A mains header tank (7) supplies all other water requirements as per normal plumbing practice.

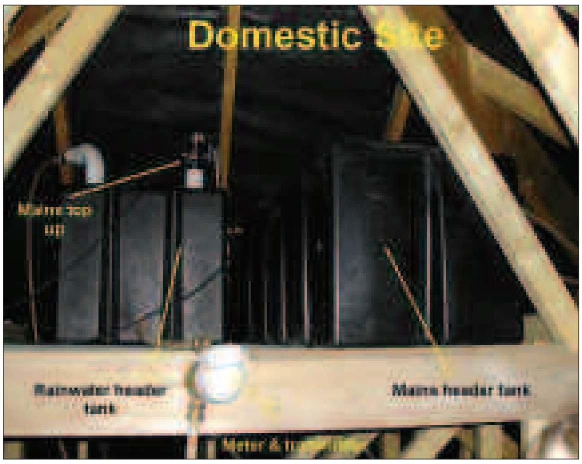


Fig. 2.2 Showing mains top-up to rainwater tank in attic.

Fig. 2.3 Underground rainwater harvesting 9m³ storage tank.

2.1.3 Installation

The rainwater harvesting system collected water from roof surfaces only. Rainwater from the downpipes was diverted to an underground Rainman 1™ filter that separated solids from the rainwater. These solids were diverted to the surface water drainage system. No first flush diversion device was installed. The harvested rainwater water drained from the roof to a $9m^3$ underground precast concrete collection tank.

All connections to the rainwater drainage system were sealed to prevent contamination from surface water. A separate plumbing supply was installed from the attic to the toilets. A submersible Multigo pump placed in the collection tank in the garden pumped the collected rainwater to the rainwater header tank in the attic. The pump's floating filter inlet lay just below the water level, preventing any floating debris entering the pump. The pump had a safety mechanism that prevented switching on if the water level in the tank was below a certain level. This protected the pump and prevented any settled material being disturbed, thus clogging the pump inlet or entering the rainwater header tank.

Rainwater was then delivered by gravity from the attic to provide water for toilet flushing and for external garden taps. In periods of low rainfall, the rainwater header tank was filled from the mains water header tank by means of a solenoid valve. A tundish type AA air gap prevented backflow to the mains water supply. A data logger system with flow monitoring was used to assess micro component household water usage. A weather station (Davis Instruments Vantage Pro™) was installed to generate water balance data (Reid et al., 2007).

Fig. 2.4 Submersible pump installed in underground rainwater storage tank.

Fig. 2.5 Inline filter installed prior to rainwater entry to tank.

Fig. 2.6 Floating suction filter installed on submersible pump.

Fig. 2.7 Sealed downpipe to rainwater catchment system.

Fig. 2.8 Pressure meter showing level of rainwater in storage tank.

2.1.4 Management of the RWH system

To control and ensure the smooth running of the system, a control management system was installed. A float switch was used to monitor and control the supply of harvested rainwater to the attic storage tank. When the level of the float switch fell, it signalled to the management system to pump rainwater from the underground collection tank to the rainwater storage tank in the attic. If, during periods of dry weather, there was insufficient rainwater available in the collection tank, the pump signalled the management system. In this case, the management system opened a solenoid valve to allow mains water top up the rainwater tank, thereby ensuring sufficient water at all times for toilet flushing. This mains top-up device employed an air gap and tundish, ensuring that there cross-contamination between the rainwater and the mains plumbing system was prevented.

2.1.5 Control Houses

A metering plan as shown in Figure 2.9 was designed for monitoring water use within the control houses (mains water supply only). The meters used were Bonyto Klasse C 1.5m^3/h type. Meter 1 (M1) monitored the mains demand within the household, M2 recorded water used in toilet flushing, M3 and M4 measured cold and hot water use respectively in the household at sinks and bath taps and any appliances such as washing machines and dish washers.

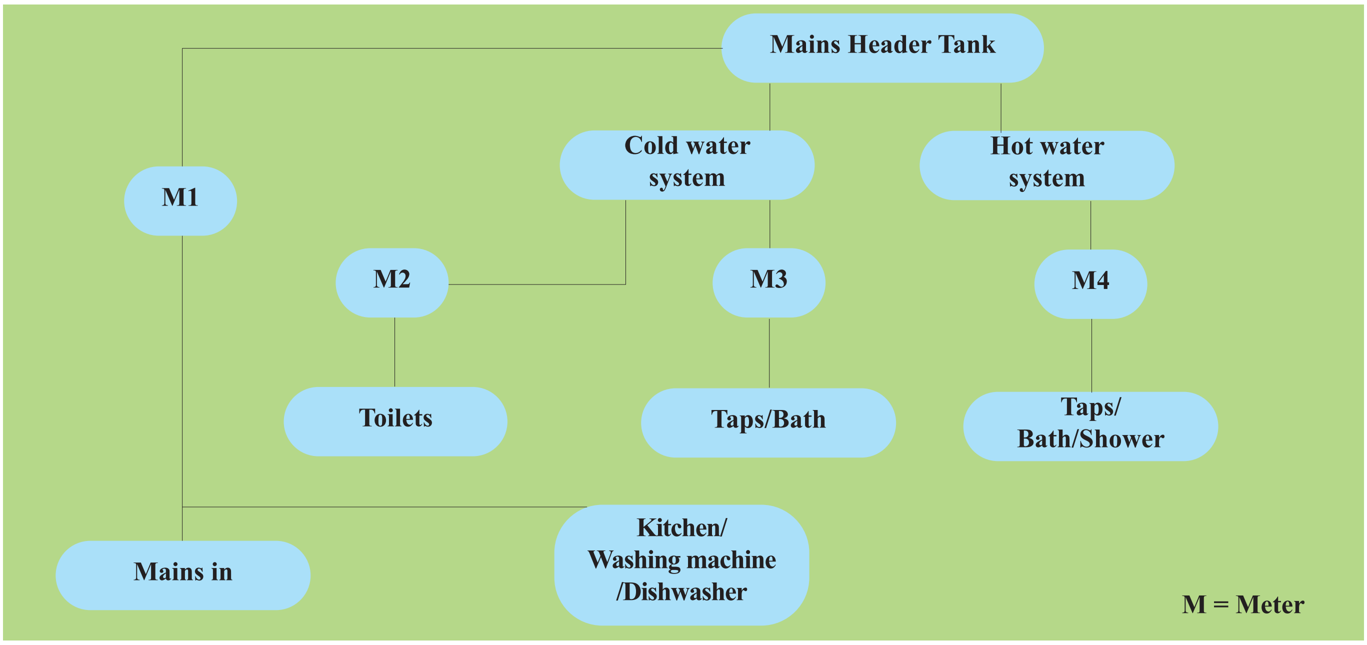


Fig. 2.9 Metering installations.

2.1.6 Rainwater Harvesting House

A metering plan as shown in Figure 2.10 was designed for monitoring water use within the dual supply house (rainwater & mains water supply). Meters M1 – M4 monitored the same water parameters as in the five control houses. Two additional meters, M5 and M6, were installed, one (M5) to monitor rainwater transferred from the collection tank to the rainwater header tank in the attic and the other (M6) measuring the volume of mains top-up entering the rainwater header tank.

2.1.7 Meter Operational & Installation Specifications

The metering system installed in all four houses in Phase 1 consisted of four meters (Bonyto Klasse C 1.5m^3/h type). M1 was placed under the kitchen sink on the mains pipe to the house. This measured total mains water use. Meters M2, M3 and M4 were located in the hot press (airing cupboard), measuring toilets, cold water demand and hot water demand respectively (Figs 2.11 & 2.12). As stated above, M5 measured rainwater flow to the storage tank from the collection tank in the garden, while M6 measured the mains top-up to the rainwater storage tank. This mains water top-up facility ensured that sufficient water was available for toilet flushing during periods of dry weather. If there was insufficient rainwater in the collection tank, the mains top-up was switched on via the water management system.

Meters measuring the mains into the house were situated in the path outside (Fig 2.13).

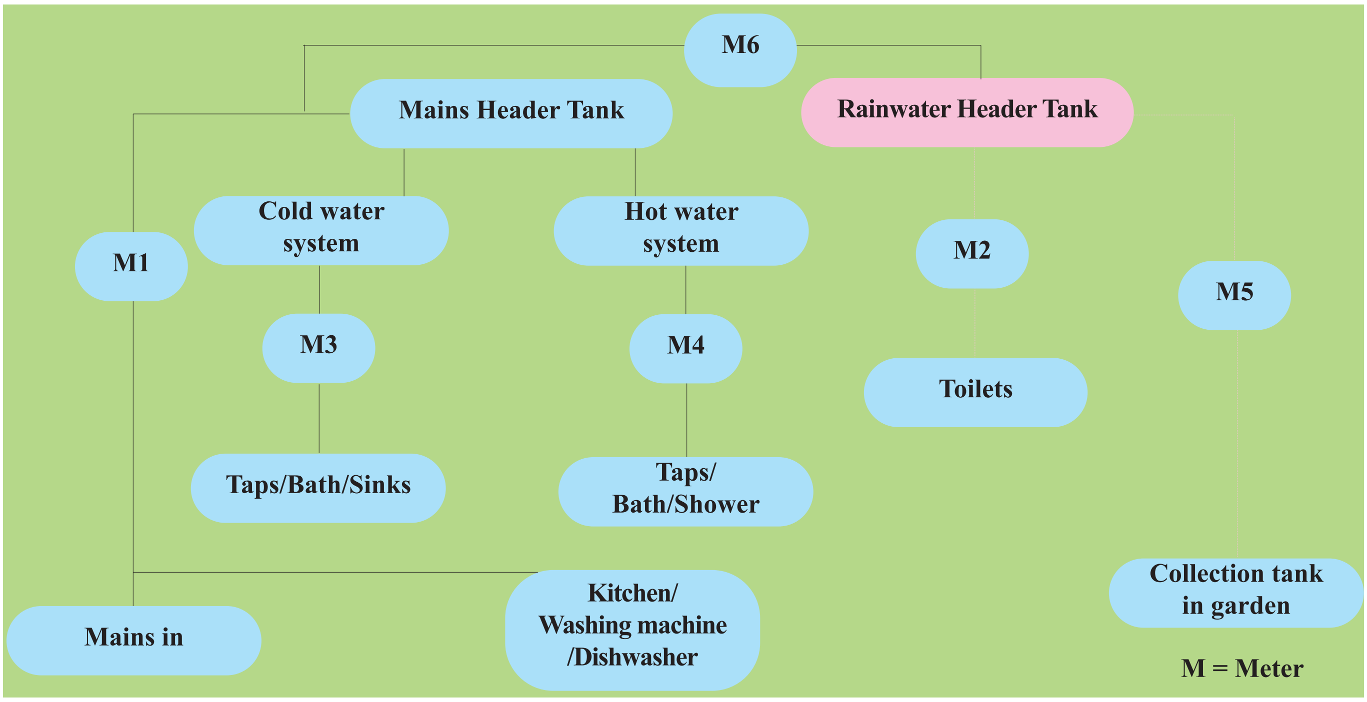


Fig.2.10 Metering schematic for initial rainwater harvesting house.

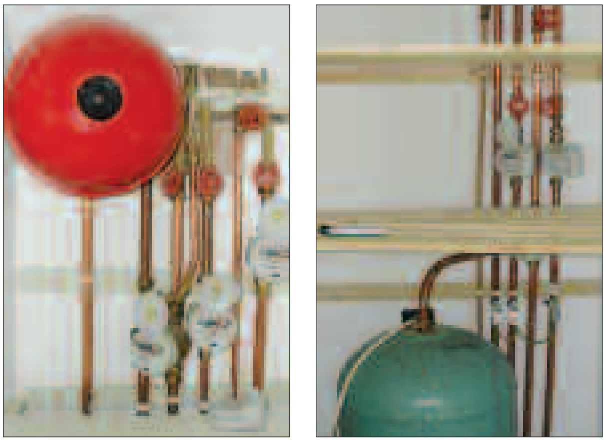


Fig. 2.11 & 2.12 Water meters in the hot press.

Fig. 2.13 Meter with attached transmitter located externally.

2.1.8 Flow Data Collection Methodology

To minimise disruption to the householders, a remote monitoring system was installed in the houses. This consisted of Hydrometer's Hydro-Centre. Flow meters were fitted with a radio transmitter, allowing meter data to be transmitted to the Hydro-Centre's data logger for storage. Each meter's reading was transmitted to and stored by the Hydro-Centre 4 times per day: at 00:00, 06:00, 12:00 and 18:00. The Hydro-Centre had mobile phone SIM card technology facilitating the remote downloading of stored data via telephone and Hydrometer's software package, Hydro-Centre 2.35. Due to site conditions, one Hydro-Centre was incapable of picking up the transmitted meter readings from all 4 houses. Therefore, two Hydro-Centres were employed: one was set up in one of the control houses, the second in the RWH house.

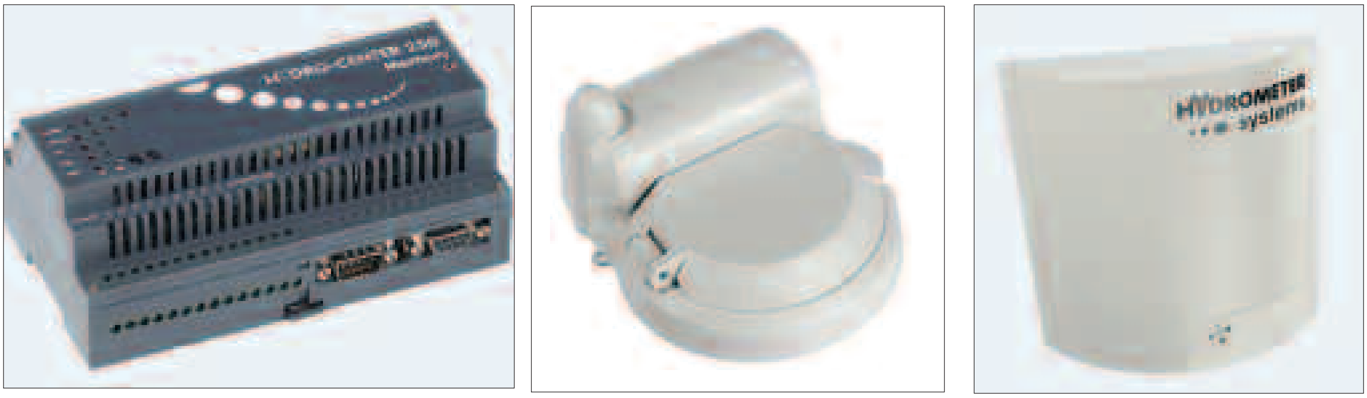


Fig. 2.14 Hydro-Centre, radio transmitter and transceiver.

The instrumentation used to collect and store meter readings is shown in Fig 2.14. The transceiver picked up the signal transmitted by the radio transmitter attached to the meter and sent it to the Hydro-Centre for storage. This stored data was then downloaded via a telephone line and computer programme for analysis.

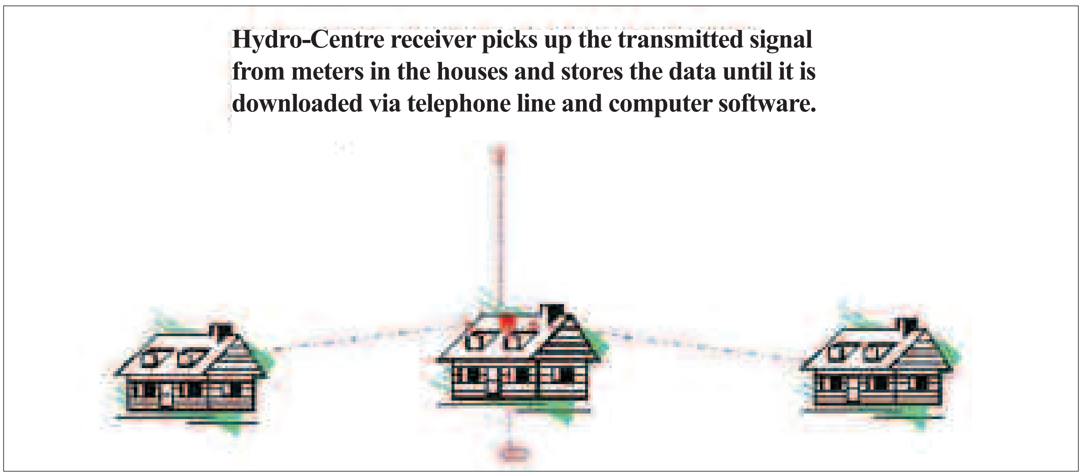


Fig. 2.15 Schematic showing data collection and retrieval.

2.1.9 Weather Data

A Vantage PRO2™ Weather Station was set up close to the houses to monitor local weather, data being downloaded every 6 weeks.

2.2: DOMESTIC HARVESTED RAINWATER QUANTITY RESULTS

Table 2.2 shows results of water use and demand in Carlow over the 22 month monitoring period (March 2006 to January 2008). The RWH house had an occupancy of one adult and one child. The per capita consumption (PCC) was 77 litres per head per day (l per hd-d). The mains use was 87m^3, comprising 11m^3 of cold water, 30m^3 of hot water and kitchen use of 46m^3. Toilet use was 20m^3, which was supplied by the RWH system, except for a brief period when a ballcock jammed.

House	Mains water m^3	Number of inhabitants	PCC l per hd-d	Toilets m^3	Cold water m^3	Hot water m^3	Kitchen m^3
House RWH	87	2	77	20	11	30	46
House 2	430	5	125	112	62	70	186
House 3	173	3	84	39	22	29	83
House 4	503	5	157	236	49	74	144

Table 2.2 Water use and demand in Carlow over the 22 month monitoring period Mar 06 – Jan 08.

House 2 had an occupancy of five, two adults and three children. The PCC was 125 l per hd-d. The household showed mains consumption of 430m^3. This comprised of 112m^3 for toilet use, 62m^3 for cold water use, 70m^3 for hot water and 186m^3 for kitchen use. House 3, had an occupancy of three, two adults and one child. The PCC was 84 l per hd-d. The household showed mains consumption of 173m^3, comprising toilets 39m^3, cold water 22m^3, hot water 29m^3 and kitchen use of 83m^3. House 4, had an occupancy of five, two adults and three children. The PCC was 157 l per hd-d. The household showed mains consumption of 503m^3, comprising 236m^3 for toilets, 49m^3 for cold water, 74m^3 hot water and 144m^3 for kitchen use. The value of 236m^3 for toilets included a period where a faulty valve in one toilet in the house caused the toilet cistern to run continuously. Table 2.2 shows monthly rainfall, harvestable rainfall and the demand for toilet water in the RWH house.

For the period monitored in 2006, monthly harvestable rainfall was greater than toilet demand, with the exception of July where harvestable rainfall was 0.5m^3 and demand 1.1m^3. The excess supply over demand from March to June 2006 (9.2m^3) allowed sufficient rainwater to be stored to cover the shortfall in July. Also, over this period demand totalled 8.5m^3 while potential harvestable rainfall totalled 35.2m^3. Therefore, 26.7m^3 of rainwater was potentially available for use. In 2007, the supply of monthly harvestable rainfall exceeded monthly demand except during January, April and July.

2006	J	F	M	A	M	J	J	A	S	O	N	D	Total
Rainfall mm			91	31	98	28	10	41	92	80	114	112	695.5
Harvestable Rainfall m^3			4.6	1.5	5	1.4	0.5	2.1	4.6	4	5.8	5.7	35.2
Toilet Demand m^3			0.7	1.1	1	0.5	1.1	1	0.6	0.9	0.8	0.8	8.5
2007	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**
Rainfall mm	12	71	58	10	38	41	9.8	83	38	21	45	84	509.8
Harvestable Rainfall m^3	0.6	3.6	2.9	0.5	1.9	2.1	0.5	4.2	1.9	1.1	2.3	4.3	25.9
Toilet Demand m^3	0.7	0.6	1.1	0.7	0.7	1.1	1	0.8	1	0.8	0.7	0.8	10.0
2008	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**
Rainfall mm	120	38	53										210.6
Harvestable Rainfall m^3	6.1	1.9	2.7										10.7
Toilet Demand m^3	0.7	0.6	0.3										1.6

Table 2.3 Rainfall, harvestable rainfall and toilet demand between March 2006 – March 2008.

January's shortfall was covered due to excess supply over demand during the last months of 2006. April and July's shortfall were similarly met due to excess harvestable rainfall available in the preceding months. Over 2007, 15.9m^3 of rainwater were captured in excess of the demand placed for toilet water. As a result of this excess, the collection tank was full for long periods and potentially harvestable rainfall was lost by overflow to the surface drainage system.

Over the first three months of 2008, captured rainwater exceeded the demand for toilets. Demand for mains water differed between the four households (Table 2.2). The average PCC for the four houses was 111 l per hd-d. The breakdown of water use patterns within households also varied, as shown in Fig. 2.16. Mains water for kitchen use ranged between 41-47%, cold water use between 10-14%, hot water use ranged between 14-28%.

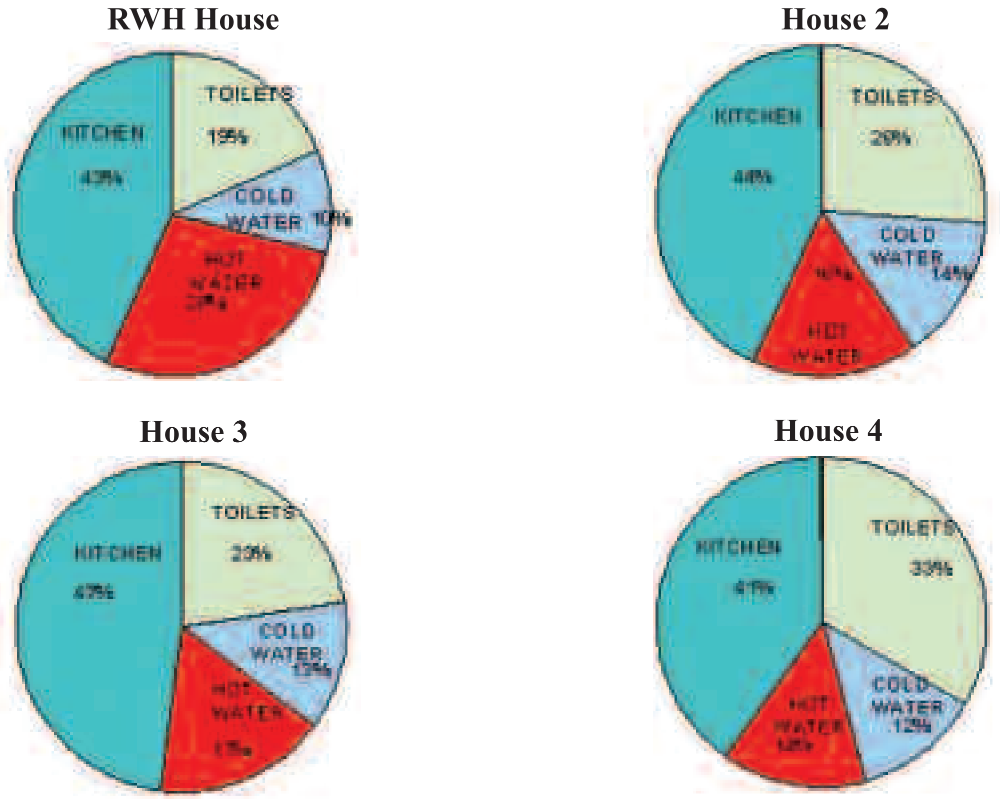


Fig. 2.16 Water use within households.

2.2.1 Discussion of Results

Over the 22 month monitoring period, the RWH system supplied 20m^3 of rainwater which met the demand for toilet flushing in the RWH house. This is equivalent to a saving of 19% of mains water supplied to the house. From rainfall figures over the same period, the RWH system could have supplied 71.8 m^3 of water. Thus 51.8m^3 of rainwater was potentially available for household use.

In the four monitored houses, toilet demand varied between households from 19% to 33% of mains water use. Table 2.4 shows toilet demand for each house and the percentage of this demand potentially met by harvestable rainfall. This was determined after plotting monthly toilet demand versus monthly harvestable rainfall. In the RWH house there was always rainwater available for the toilets. In the control houses toilet demand exceeded harvestable rainfall in some months. Also while 71m^3 of rainwater was available it was not available uniformly throughout the year. Toilet demand also varied throughout the year. In the case of House 4, toilet demand was distorted by a leak.

House	Toilet demand m^3	Percentage potentially met by RWH system
House 1 RWH	20	100%
House 2	112	71%
House 3	39	100%
House 4	236	37%

Table 2.4 Percentage of toilet demand that could potentially be supplied by the installed RWH system.

2.2.2 Conclusions

- In the domestic situation, rainwater harvesting has a significant role to play in reducing mains demand.
- Rainwater can, depending upon demand for toilet use, substitute between 37-100% of mains water for toilet flushing facilities. This in turn leads to an overall saving of between 19-33% reduction in demand for mains water.
- Such reduction in mains water demand, if multiplied over a large number of houses, would lead to substantial savings in water for the producer, in this case Ballinabrannagh Group Water Scheme. This may reduce the need to develop new water sources while at the same time increasing the capacity of existing sources to supply more members.

2.3 DOMESTIC HARVESTED RAINWATER QUALITY RESULTS

2.3.1 Testing Methodology

Rainwater from the underground reservoir was sampled monthly for nineteen months between January 2006 and July 2007. Samples were taken aseptically and transported to the laboratory within 4 hours and were stored between 2-8ºC in accordance with ISO/IEC 17025:2005 (ISO 17025, 2005). 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 as per Standard Methods (Standard Methods, 2005). 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) (No. 2) Regulations, S.I. No. 278 of 2007. However, the majority of these pollutants only arise in water treatment processes or when water is flowing through rock and soil. Although it was not necessary to monitor for all of these parameters, one full audit suite of testing was carried out.

2.3.2 Physico-chemical Water Quality

The physico-chemical results for the domestic site are shown in Table 2.5. There are currently no specific national guidelines applying to the use of rainwater for domestic supply. Results for the harvested rainwater quality are compared with the European Communities (Drinking Water) (No. 2) 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 Drinking Water Regulations and Bathing Water Regulations respectively). It was considered an important function of the project to collect data on raw harvested rainwater. For this reason, no disinfection programme was carried out at any stage in the rainwater harvesting process and no first flush device was fitted to the system.

There are no limits for Sulphate and Nitrate parameters in the Bathing Water Regulations but the results for these parameters are significantly lower than the limits set down in the Drinking Water Regulations. Nitrite is slightly below the limit of 0.50 mg/l in drinking water with a maximum of 0.49 mg/l. Ammonia as NH_3 demonstrated a mean of 0.12 mg/l with a minimum of 0 and a maximum of 0.77 mg/l. These results are below the limits for both drinking and bathing water. Total Dissolved Solids (TDS) showed a mean value of 84.63 mg/l, with a minimum of 6.00 and a maximum of 189 mg/l while Total Suspended Solids (TSS) showed a mean of 5.37 mg/l with a minimum of 0 and a maximum of 25 mg/l. Neither of these parameters is cited in the Drinking Water or Bathing Water directives. Turbidity gave a mean result of 1.10 NTU (nephelometric turbidity units) with a minimum of 0 and a maximum of 4.60 NTU. The Drinking Water legislation requires that the turbidity of the water shows no abnormal change and is acceptable to consumers.

Parameters	Units	Mean	Min	Max	SD	Median	Drinking Water Regs	Bathing Water Regs
Chloride	mg/l	5.73	1.50	22.49	4.86	5.06	250 mg/l	
Nitrates NO_3	mg/l	1.14	0.00	2.84	0.97	1.24	50 mg/l	
Nitrite as NO_2	mg/l	0.06	0.00	0.49	0.11	0.03	0.50 mg/l	
Sulphate	mg/l	8.66	0.00	31.70	9.32	7.50	250 mg/l	
Ammonia NH_3	mg/l	0.12	0.00	0.77	0.20	0.05	0.28 mg/l	
pH	pH Units	7.24	6.26	8.21	0.55	7.21	6.5 - 9.5	6.0-9.0
TDS	mg/l	84.63	6.00	189.00	39.43	77.00		
TSS	mg/l	5.37	0.00	25.00	5.78	4.00		
Turbidity	NTU	1.10	0.00	4.60	1.21	1.11	NAC&ATC*	
Sodium	mg/l	4.15	0.00	8.60	3.13	4.60	200 mg/l	
Calcium	mg/l	13.32	3.10	23.20	5.35	14.00	None	
Lead Total	µg/l	5.74	0.00	25.32	7.82	1.98	10 µg/l **	
Iron Total	µg/l	25.66	0.00	95.03	25.25	21.73	200 µg/l	
Cadmium Total	µg/l	0.03	0.00	0.30	0.08	0.00	5.0 µg/l	

* No abnormal change and acceptable to consumers

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

Table 2.5 Overall Physico-chemical results for the harvested rainwater based on 19 monthly samples taken between January 2006 and July 2007.

Metals results were all within the limits set out in the Drinking Water Regulations with the exception of Lead. There is no legislation governing the concentration of Calcium in either the Drinking or Bathing Water Regulations. The Iron results showed a mean of 25.66 µg/l, a minimum of 0 and a maximum of 95 µg/l. This is below the 200 µg/l maximum allowed in drinking water. Total Cadmium demonstrated a mean of 0.03 µg/l, a minimum of 0 and a maximum of 0.30 µg/l. Cadmium is not cited in the Bathing Water Regulations,while the parametric value for Drinking Water is 5.0 µg/l. Of all the physic-ochemical parameters tested, all complied with the Bathing Water Regulations, while two were in breach of Drinking Water Regulations; Lead with a maximum of 25.32 µg/l and pH where a minimum of 6.26 was recorded in one sample.

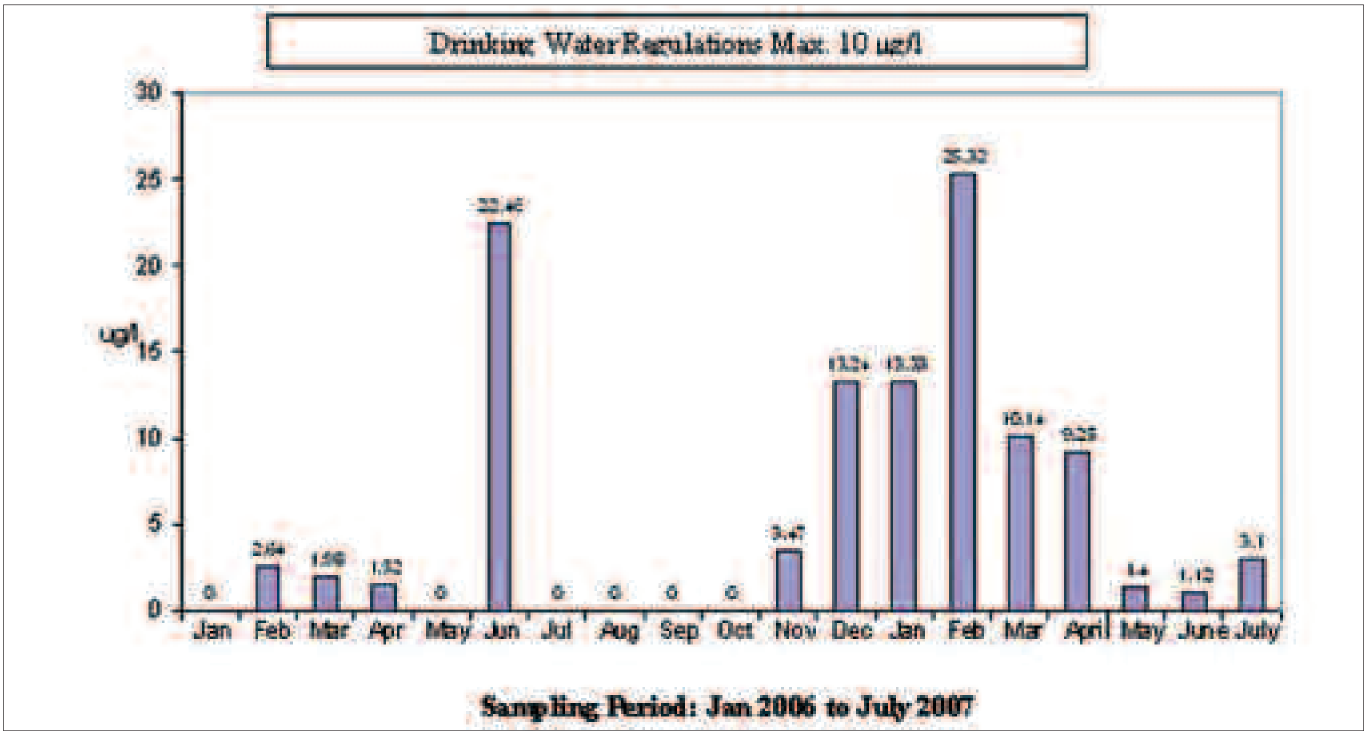


Fig. 2.17 Harvested Rainwater Quality Results for Lead from Jan 2006 to July 2007. Sampling Period: Jan 2006 to July 2007.

2.3.3 Microbiological Water Quality

Table 2.6 presents the microbiological monitoring results for the domestic site over the 19 months of sampling between January 2006 and July 2007. Coliforms had a maximum of 1203.3 MPN/100ml, a minimum of 0.00 and a mean of 216.83 MPN/100ml. There should not be any coliforms detected in a drinking water sample according to European Drinking Water Regulations. Therefore, both the mean and maximum results are in breach of these regulations. However, the maximum concentration allowed in a Bathing Water sample is 5000 MPN/100ml, meaning that the results are within the limits with reference to the Bathing Water Regulations.

Parameters	Units	Mean	Min	Max	SD	Median	Drinking Water Regs	Bathing Water Regs
Coliforms	MPN/100ml	216.83	0.00	1,203.30	346.56	365.4	0 no./100ml	5000/100ml
E coli	MPN/100ml	0.39	0.00	7.50	1.72	3.75	0 no./100ml	1000/100ml
Faecal Coliforms	-Cfu/100ml	3.00	0.00	22.00	7.21	0.00	-	1000/100ml
TVC @ 22ºC	Cfu/ml	3,264.11	1.00	35,400.00	8,178.81	546.50	NAC*	-
TVC @ 37 ºC	Cfu/ml	216.26	3.00	704.00	215.08	169.00	NAC*	-
Pseudomonas spp	Cfu/100ml	6.00	0.00	80.00	19.43	15.00		
* NAC = No abnormal change								

Table 2.6 Overall microbiological results for the harvested rainwater based on 19 monthly samples taken between January 2006 and July 2007.

The maximum result for *E. coli* was 7.50 MPN/100ml, the minimum was 0.00 and the mean was 0.39 MPN/100ml. The Drinking Water Regulations require that the water be free from *E. coli*, with the bathing water regulations specifying an allowable limit of 1,000 MPN/100ml. Faecal coliforms were also detected with a maximum of 22.00, a minimum of 0 and a mean of 3. TVC at 22ºC showed a maximum of 35,400, a minimum of 1.00 and a mean 3,264.11 cfu/ml and TVC at 37ºC had maximum of 704, a minimum of 3.00 and a mean of 216.26 cfu/ml. Pseudomonas spp had maximum result of 80 cfu/100ml, a minimum of 0.00 and a mean of 6.00 cfu/100ml.

Table 2.7 presents a summary of the microbiological results after the first six months of operation. This shows that 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. The TVCs at 22ºC had a maximum result of 3000 cfu/ml, a minimum of 1.00 and a mean 975.00 cfu/ml. TVCs at 37ºC reached a maximum result of 704 cfu/ml, a minimum of 3.00 and a mean of 241.71 cfu/ml. Pseudomonas spp showed a maximum result of 80 cfu/100ml, a minimum of 0 and a mean 7.92 cfu/100ml.

Parameters	Units	Mean	Min	Max	SD	Median	Drinking Water Regs	Bathing Water Regs
Coliforms	MPN/100ml	0.00	0.00	0.00	0.00	0.00	0 no./100ml	5000/100ml
E coli	MPN/100ml	0.00	0.00	0.00	0.00	0.00	0 no./100ml	1000/100ml
Faecal Coliforms	-Cfu/100ml	0.00	0.00	0.00	0.00	0.00	-	1000/100ml
TVC @ 22ºC	Cfu/ml	975.00	1.00	3000.00	1234.98	300.00	NAC*	-
TVC @ 37 ºC	Cfu/ml	241.71	3.00	704.00	243.34	183.50	NAC*	-
Pseudomonas spp	Cfu/100ml	7.92	0.00	80.00	23.11	0.00		
* NAC = No abnormal change								

Table 2.7 Microbiological results for the harvested rainwater based on monthly samples taken between June 2006 and July 2007, after first six months commissioning stage (i.e. the period of sampling where no faecal indicator organisms were present).

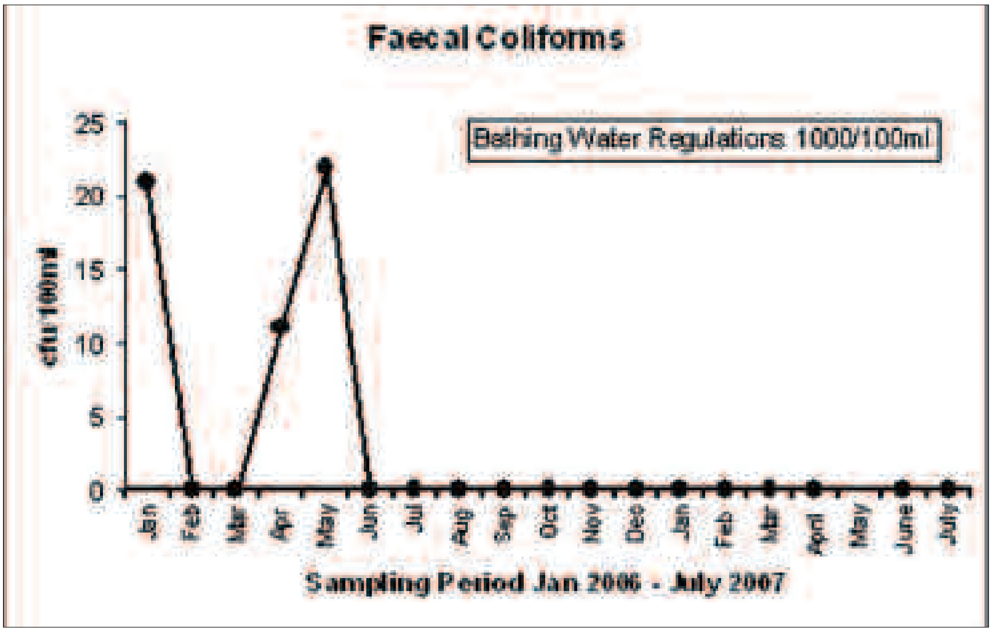


Fig. 2.18 Faecal Coliform results for Harvested Rainwater January 2006 – July 2007.

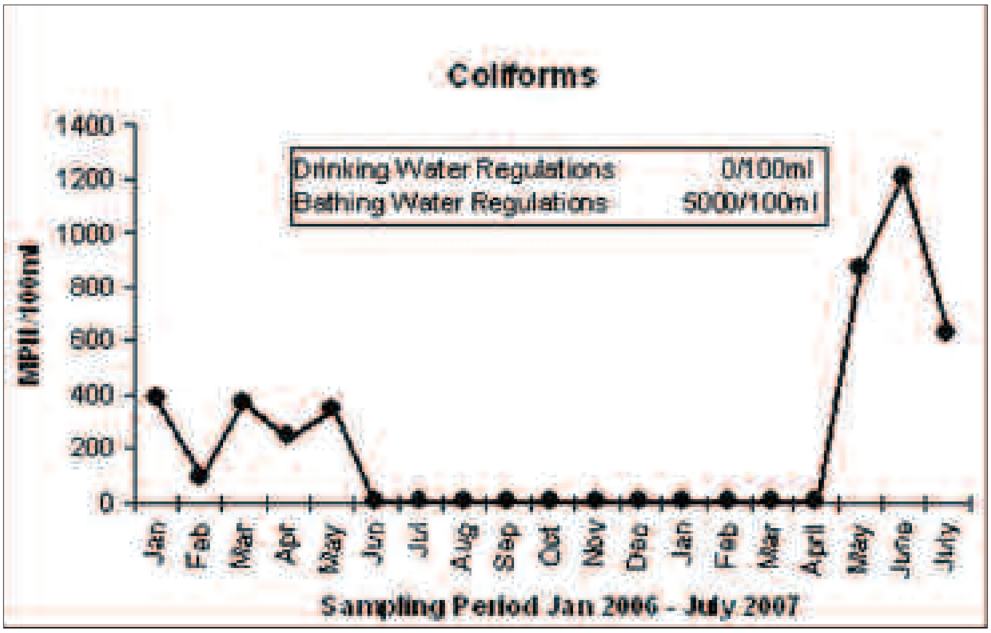


Fig. 2.19 Coliform Results for Harvested Rainwater January 2006 – July 2007.

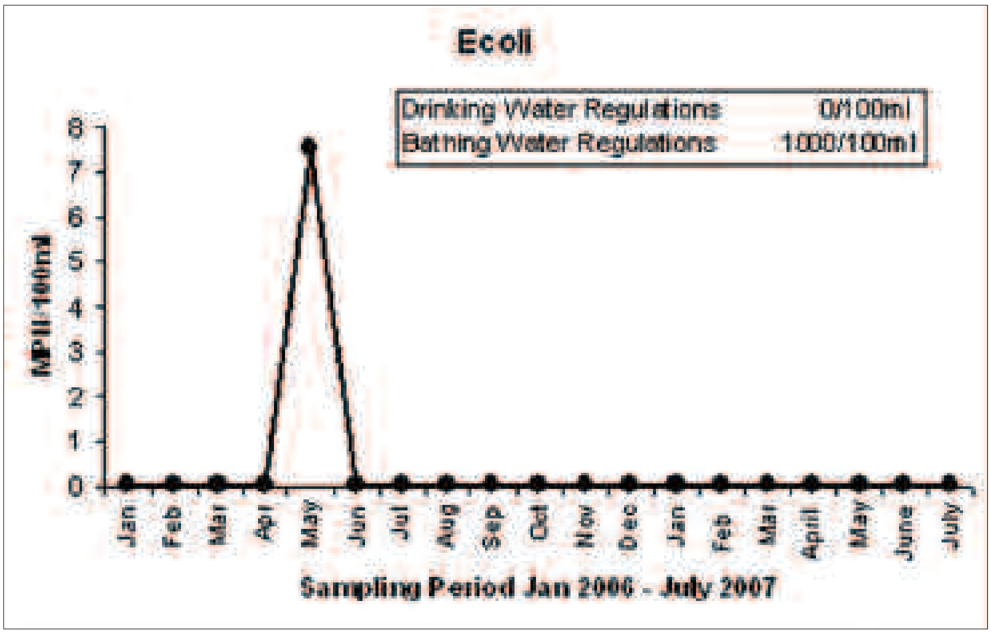


Fig. 2.20 *E.coli* Results for Harvested Rainwater January 2006 – July 2007.

2.3.4 Discussion of Results

The dual water supply system was installed at the Carlow house during August 2005 and was commissioned September/ October 2005. The house was occupied in December 2005 but the system had been operational from the previous October. A manual monitoring program to collect and analyse water samples and to measure mains water use commenced in January 2006. The automated monitoring program to measure rainfall and water levels in the tank commenced in March 2006.

2.3.5 Physico-Chemical Quality

The physico-chemical quality of harvested rainwater in Carlow was of very good quality, complying with the Bathing Water Regulations at all times. Compliance with the more stringent Drinking Water Regulations was achieved for all parameters except pH and Lead. The pH results had a mean of 7.24 pH units, with a minimum of 6.26 and a maximum of 8.21. The lower limit in the European Drinking Water Regulations is 6.5 and samples were slightly below this on three occasions, the lowest value being 6.26 in May 2006. The pH was always within the allowable range for bathing water.

Fig 2.17 illustrates the results for Lead, which had a mean concentration of 5.74 µg/l with a minimum of 0 and a maximum of 25.32 µg/l. The 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 is the flashings used on the rainwater harvesting house. The soft nature of the rainwater may have leached some lead from these flashings. Rainwater harvesting manuals recommend using an alternative metal than lead for flashings, where rainwater is to be used for purposes that involve contact with humans (Texas Guide, 1997).

2.3.6 Microbiological Quality

In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with human or animal (including bird) 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 (figures 2.18, 2.19 and 2.20). The initial period (January 2006 until June 2007) showed levels of faecal indicator organisms (coliforms, *E. coli* and faecal coliforms) present, in breach of Drinking Water Regulations. Coliforms were detected in each sample taken from January 2006 to May 2006 with *E. coli* present on one occasion and faecal coliforms present on three sampling dates.

Coliforms are classed as faecal indicator organisms but can be caused by the presence of rotting vegetation, while bird droppings washed down from the roof could account for *E. coli* and faecal coliforms. During construction of the house and installation of the rainwater harvesting system the collection tank was left open for long periods of time. This would have allowed for significant contamination to occur. Building work in the vicinity of the site continued for the duration of the sampling period, further increasing the potential for contamination.

A second trend appears from July 2006 to April 2007. During this period 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. As it was only coliforms that were detected and not *E.coli*, this indicates that the probable source of contamination was rotting vegetation. Leaves, twigs etc. may have built up in the gutters and a few days of heavy rain could have washed some of this into the collection tank. If harvested rainwater is to be used for human consumption, regular and scheduled maintenance of the system should be carried out. This should include cleaning out the gutters and periodic checking and cleaning of the filter. A first flush device could also be installed to eliminate any contamination that has collected during dry periods without rain.

There are no limits for TVCs (Total Viable Counts) in Bathing Water Regulations and 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.

2.3.7 Conclusions

1. The rainwater harvested at the domestic installation was in compliance with the Bathing Water Regulations for 100% of samples taken and was of a suitable quality for use in non potable applications.

2. Results showed that the harvested rainwater complied with the more stringent Drinking Water Regulations for 37% of samples taken.

3. These monitoring results represent a worst case scenario, as no first flush device was installed and no disinfection of the system took place.

4. An efficient disinfection programme would have ensured that the quality of the harvested rainwater was in compliance with Microbiological Drinking Water Regulations.

5. Lead flashings should not be used on any rainwater harvesting facility where water is to be used for potable applications.

6. Regular maintenance of the system is advised to ensure optimum water quality.

Fig. 2.21 The house at Ballinabrannagh, County Carlow in which the rainwater harvesting system was installed.

3.1 PILOT SITE 2: LIVESTOCK FARM, CLONALVY, COUNTY MEATH

RAINWATER HARVESTING INSTALLATIONS: Pilot Site 2: 250-acre livestock farm, Clonalvy, County Meath

- 250 acre farm
- Catchment Area: 1,910m^2
- Underground pumping tank 9m^3
- Rainwater reservoir 44m^3
- Rainwater supplies drinking troughs
- Data logger system with flow monitoring to assess micro-component household water useage
- Rainwater sampled monthly and tested in INAB accredited laboratory
- Weather station installed on site to generate water balance

The agricultural site was located at Clonalvy, County Meath, approximately 50 km from Dublin. It is a 250-acre livestock farm with 114 cattle and 50 calves as of March 2006. The farm buildings lie in the centre of the farm and the relevant buildings to the project are two sheds/barns each of approximately 1,000 m^2 roof area. Potable water is supplied to the farm by Meath County Council.

3.1.2 DETAILED DESIGN

In order to develop a water management and rainwater harvesting design for the site, a site survey consisting of level and GPS data was carried out in January and February 2005. The survey information was superimposed on a vector map of the site. This enabled site contours to be drawn. The compound is located halfway through the farm. There is a fall of over 25m from the top of the farm to the lower fields. Following on from this survey the current farm water use and costs were established.

A water use inventory was carried out to identify animal, washings and other water use. The number, type, species and age of all livestock were established. Crop protection and irrigation records were analysed. The theoretical water usage was calculated. Water bills for the last four years were viewed. The farm was not metered, mains water being paid for at a flat yearly rate. A walk-over survey established the line and level of the mains water supply to the farm. A visual inspection of all water equipment was undertaken to identify any leaks of water loss. Finally, a water management plan was prepared for the site and is currently under review with the farmer.

The aims of the plan were as follows:

- to reduce water and energy use
- reduce wastewater volumes
- improve environmental performance
- increase profit margin

3.1.3 POTENTIAL YIELD FROM RAINWATER HARVESTING

A detailed analysis of potential rainwater yield was carried out. The storm duration versus intensity profile for 1, 2, 5, 10, 20, 50 and 100 year return periods was calculated. From this data storage volumes for the individual farm buildings were established.

Building No.	1	2	3	1 + 2
Return Period	Storage Volume (m^3)			
1	15.66	17.94	5.95	41.65
2	19.86	22.6	7.35	52.37
5	22.57	29.06	10.23	66.19
10	31.28	35.93	12.52	79.25
20	38.09	43.61	15.07	94.94
50	47.55	54.11	18.64	117.02
100	56.65	64.21	22.29	139.1

Table 3.1 Design storm rainfall catchment yield volumes.

The theoretical water use analysis indicated that the farm uses 12.15m^3/d for farm washings and 10.75m^3/d for animals. In order to maximise rainwater yield a balance between supply and demand is critical. Preliminary data suggested that the farmer may only be able to augment 35% of his water supply with rainwater. The detailed design summarised three options for storage as follows:

- Reduce water usage on the farm by providing rainwater storage of 14m^3, which would be filled with a 10mm storm event falling on the roof catchment area. This would provide sufficient water storage for 2 days use.
- Provide a storage volume of 56m^3, which would be filled with a 40mm storm event. Such an event would not be statistically common in the area, particularly during the summer season.
- Provide storage volume of 9m^3 in a pumping tank and pump to a storage tank of 40m^3. This would be filled with a 30mm rainfall event falling on the roof catchment area.

The three options were assessed on cost and technical feasibility and the third option was chosen. The total rainwater storage provided was 40m^3, comprising two 22m^3 precast concrete tanks interconnected via a 100mm pipe. An overflow facility decreased the total capacity of the storage tank to approximately 40m^3. Hardcore foundations were laid for the storage tank, which is situated above ground, at an elevation of approximately 10m above the farm yard.

3.1.4 Rainwater Harvesting System

Rainwater from two sheds/barns was drained by gravity to an underground pre-cast 9m^3 concrete collection tank. A 200mm high perforated stainless steel plate, overlapped, and of diameter 75mm, was placed in the downpipe gutter, as a filter. The collection tank was fitted with a pump and float switch, and the overflow pipe was connected to an adjacent field drain. The harvested rainwater was pumped via a 25mm rising pipe to two 22m^3 pre-cast concrete reservoir tanks located on an adjacent elevated site. A mains top-up connection ensured water supply to the reservoir during periods of low rainfall. The harvested rainwater was distributed, via a 25mm pipe, by gravity to supply drinking troughs for cattle on the farm.

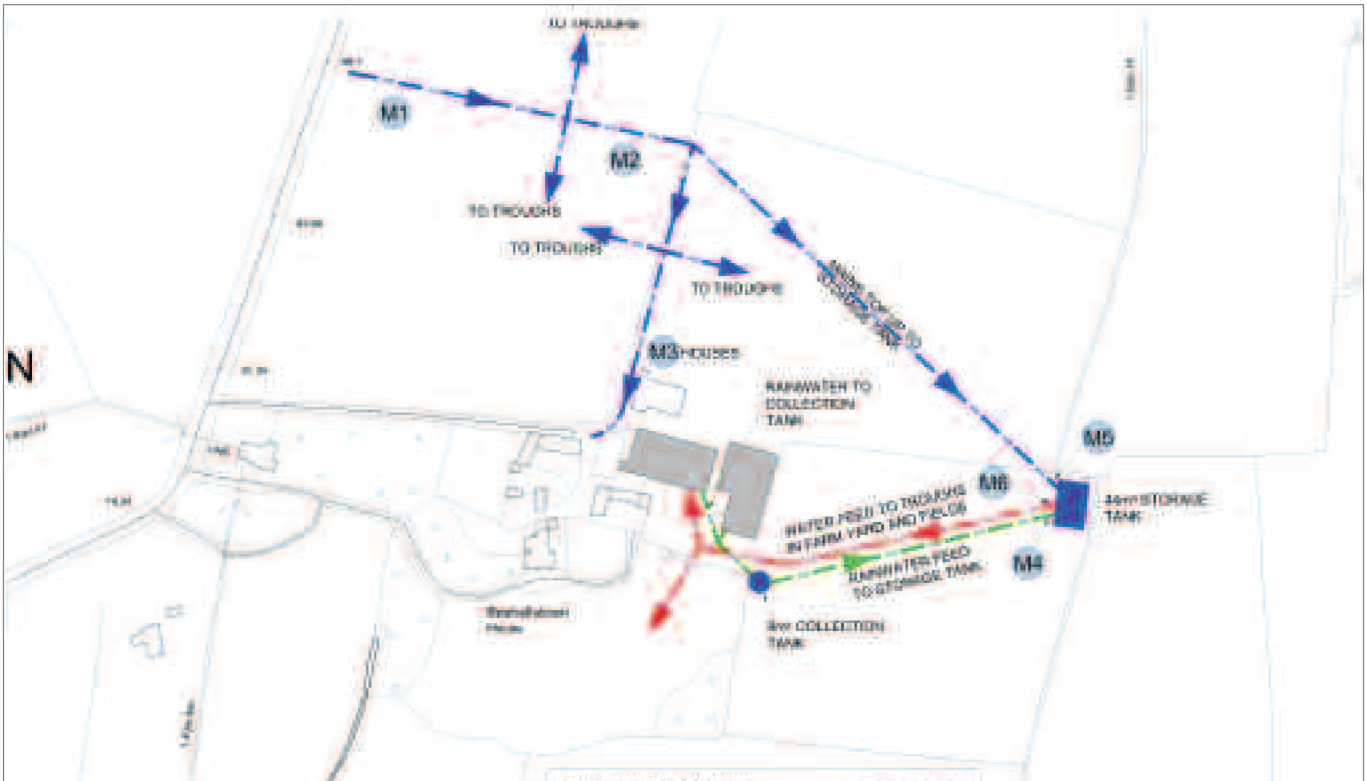


Fig. 3.1 Rainwater supply network.

Rainwater drains from the roof catchment to an underground collection tank nearby (Figs. 3.2 & 3.3). From this tank a submersible pump pumps the water up to the storage tanks.

Fig. 3.2 Roof catchment.

Fig. 3.3 Underground pumping tank.

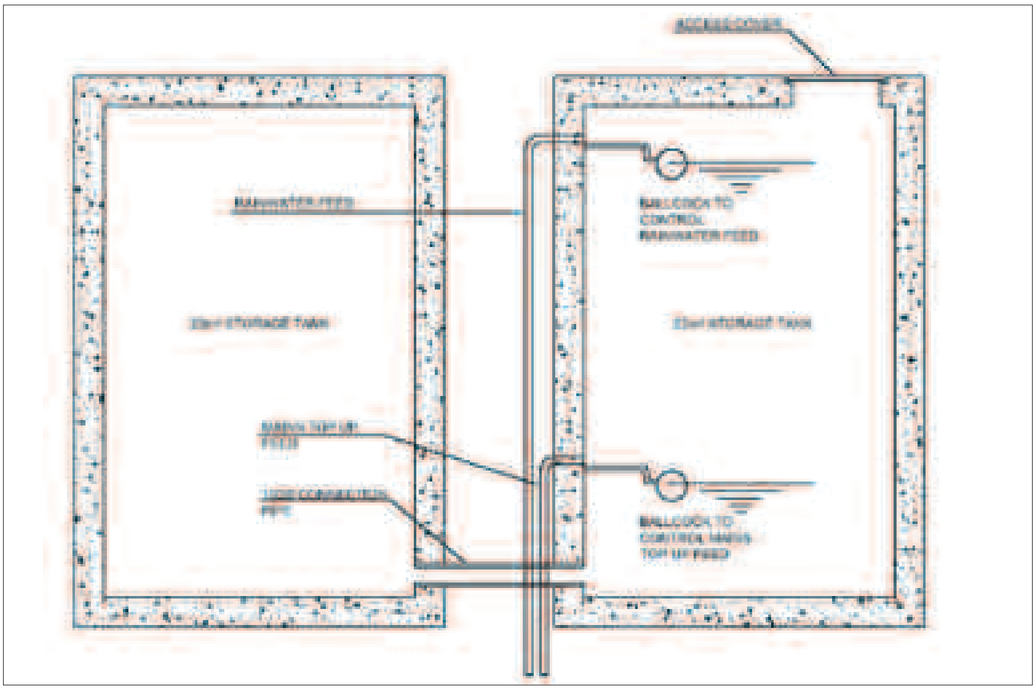


Fig. 3.4 Rainwater reservoir.

3.1.5 Rainwater Harvesting System Control

An electrical control panel connected to the pump in the collection tank was installed in the farm building adjacent to the collection tank. Ballcocks were used to control the movement of water within the RWH system; these were connected to the control panel. Two ballcocks were installed in the storage tank; one to control the infilling of rainwater from the collection tank, the second to control flow of mains water to top up the system. (Figure 3.4) The ballcock controlling the rainwater flow to the storage tank was set at approximately 3m above the tank floor. It controlled the pump in the collection tank, switching it on and off as required. The second ballcock was installed at approximately 1m above the tank floor providing mains water back up to the storage tank. This ensured water supply to the cattle troughs during periods of dry weather when there was insufficient rainwater available, or in the event of pump failure. A red light connected to the control panel provided a quick visual check that the pump was functioning properly. Water to the farmyard troughs and some of the field troughs was distributed by gravity.

There was a facility for top-up by mains water in times of low rainfall. This was controlled by a ballcock system. If the water fell below a set level, the mains controlling ballcock was switched on. Fig. 3.7 shows the inlet for the mains pipe, the second pipe is for the rainwater, where the ball cock controlling rainwater flow is set at much higher level, allowing for maximum rainwater storage.

Fig. 3.5 Rainwater storage reservoir.

Fig. 3.6 Rainwater supply to drinking troughs by gravity system from storage reservoir.

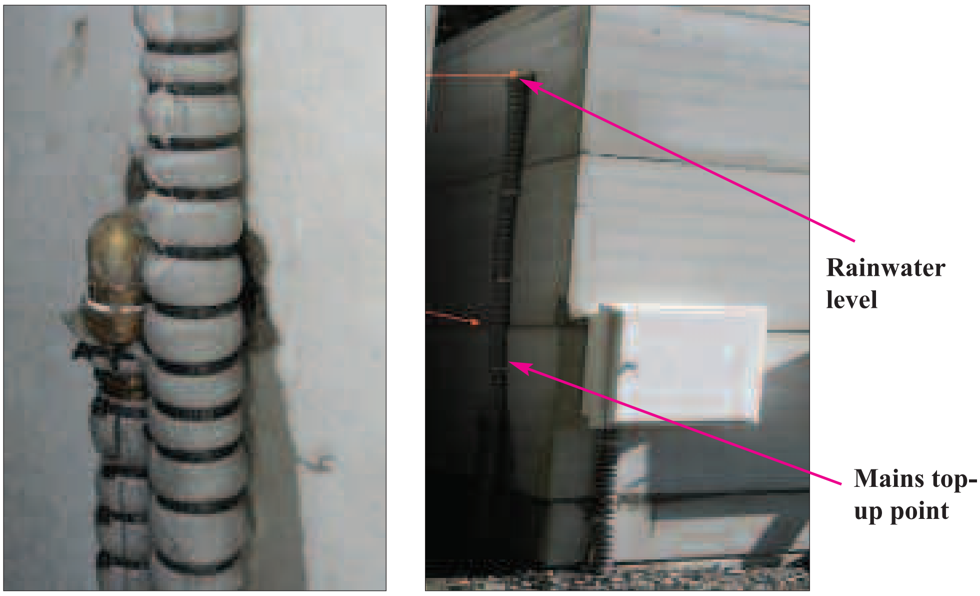


Fig. 3.7a & b Mains water top-up system.

Fig. 3.8a&b Rainwater reservoir water quality sampling points.

Fig. 3.9 Weather station at Clonalvy.

On the side of one of the tanks were sampling points (Fig. 3.8a & b) from where the quality of the water going into the storage tank and leaving the tanks going to the cattle troughs could be analysed. Both chemical and microbiological tests were performed on the water. As at the Carlow site, weather data was collected (Fig. 3.9). See Appendix for monthly rainfall data.

3.1.6 Revisions to Rainwater Filtration System

Due to the unsatisfactory performance of elements of the original installation, it was decided to alter components of the Rainwater Harvesting system. A Lindab leafbeater ™ and a BRAE ™ filter were installed on the three downpipes conducting the rainwater, via the underground pipe work, to the collection tank. The leafbeater was installed prior to the BRAE filter. The design of the leafbeater is such that it allows for the removal of larger solids, while the fine filter on the BRAE traps the finer particles. Installation of the filters required cutting the downpipes. This allowed a reduction in the pressure of the water in the pipe work. The leafbeater is self cleansing while the BRAE filter requires periodic cleaning of a removable mesh. The fine filter on the pump in the collection tank was also replaced. Armstrong Junctions (AJs) covering the underground pipe work in the farmyard were sealed, using a silicon sealant. A data logger system was also installed with flow monitoring to assess water usage.

Fig. 3.10 Build up of leaves in gutter leading to failure of custom made filter.

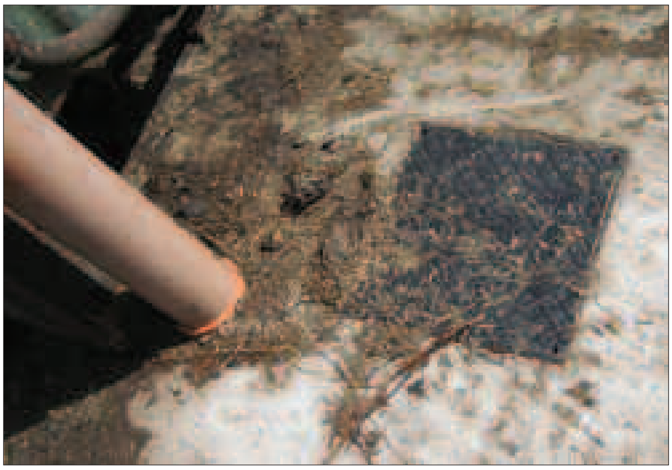


Fig. 3.11 Farm yard pollution to rainwater system.

Fig. 3.12 Installation of regime 2.

Fig. 3.13 and Fig. 3.14 A Lindab leafbeater ™ and a BRAE ™ filter installed.

3.1.7 Monitoring System for Agricultural Water Demand

A metering system was installed to measure the mains and rainwater water consumption on the farm. Harvested rainwater was exclusively supplied to the drinking troughs for cattle. Figure 4.7 shows the positioning of meters (M1, M2 etc) and their function. The meter functions are as follows;

- M1 measured all municipal water supply to the farm.
- M2 measured municipal supply to the farm, minus water supplied to troughs between M1 and M2.
- M3 measured the municipal water to the three houses on the farm.
- M4 measured the rainwater feed from the 9m^3 collection tank to the 44m^3 storage tank.
- M5 measured the municipal water supplied as to up in periods of low rainfall to the 44m^3 storage tank.
- M6 measured the water fed from the storage tank to the cattle troughs connected to the RWH system. This measurement (M6) was exclusively harvested rainwater in periods of rainfall.

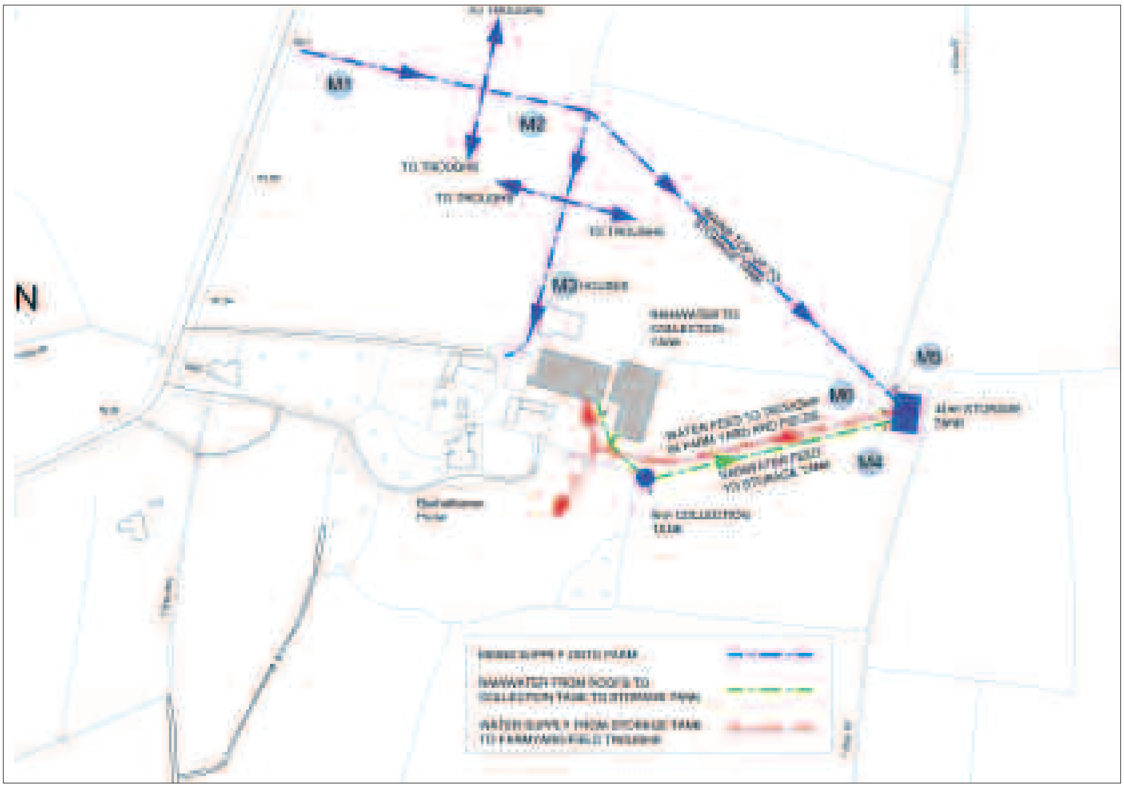


Fig. 3.15 Showing location of flow meters (Backround Map Source: OS Map No. 2648).

The meters used were Bonyto Klasse C 1.5m^3/h type. Each meter was connected to an Endress + Hauser MinilogB data logger. Meter readings were recorded and stored by the data logger at 4-hourly intervals. This stored data was downloaded via a laptop and the Endress + Hauser software ReadWin 2000. To monitor local weather patterns, a Vantage PRO2™ Weather Station from Davis Instruments was installed on the farm. Using the software package Weatherlink, the weather data stored by the station's data logger was downloaded once every 6 weeks.

3.2 AGRICULTURAL HARVESTED RAINWATER QUANTITY RESULTS

Table 5.4 shows water use on the farm over the 16 month period December 2006 to March 2008. Difficulties with commissioning the Minilog data system caused delays in acquiring water use data. Municipal water supplied by Meath County Council over the monitoring period totalled 1,704m^3. This consisted of 70m^3 in December 2006, 1,524m^3 over the 12 months of 2007 and almost 110m^3 from January to March 2008. 1,372 m^3 mains water was supplied to the three houses on the farm, 234.8m^3 mains top-up to the rainwater storage tank and 96m^3 to the farmyard and field troughs not connected to the RWH facility.

The mains top-up supplied water during periods of low rainfall and/or pump downtime. The filter device installed proved inefficient and was eventually removed by the farmer. As a result, difficulties arose with the pump between June and November 2007 due to the floating filter inlet being damaged by particulate matter entering the collection tank.

A consequence of this was a greatly reduced volume of rainwater harvested during 2007. In the second regime where Lindab leafbeaters™ and BRAE filters™ were fitted, problems with the pump were eliminated. Table 5.4 also shows harvested rainwater pumped from the collection tank to the storage tank. This totalled 215.2m^3, comprising 57.3m^3 in December 2006, 101.6m^3 during 2007 and 56.3 m^3 between January and March 2008.

	Month	Mains supply to farm m³	Mains supply to house m³	Rainwater to storage tank m³	Water to troughs m³	Mains supply top-up m³
2006	December	69.976		57.256	95.283	
2007	January	66.307		41.546	59.82	
	February	109.996		29.153	29.192	
	March	185.641		10.417	36.613	
	April	152.222		6.53	30.999	
	May	151.578		1.558	37.266	
	June	146.105		0	61.909	
	July	105.37		0	14.086	
	August	159.327		0	21.773	
	September	172.036		0	22.206	
	October	118.909		0	4.945	
	November	95.066		0.031	18.726	
	December	61.817		12.408	14.031	234.833
2008	January	41.187		24.563	16.947	
	February	40.755		14.068	25.484	
	March	27.783	1,372.31	17.715	15.47	0
Total		1,704.075	1,372.31	215.245	504.750	234.833

Table 3.2 Water demand and water use on Clonalvy farm between December 2006 – January 2008.

Water supplied from the storage tank to the troughs was 95.3m³ in December 2006, 351.6m³ during 2007 and 57.9m³ in 2008. The meter monitoring water use to the houses was manually read and the results are given in Table 5.2. Total mains water top-up has been given for the period. No mains water has been required since January 2008; all demand at RWH connected troughs has been met by rainwater supply.

2006	J	F	M	A	M	J	J	A	S	O	N	D
Rainfall mm												72.8
Harvestable Rainfall m³												93.4
Demand m³												95.28
2007	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Rainfall mm	62	34.2	26.8	9.8	45.2	60.2	67	46.8	19.4	30	38.2	48.8
Harvestable Rainfall m³	79.5	43.9	34.4	12.6	58.0	77.2	85.9	60.0	24.9	38.5	49.0	62.6
Demand m³	59.82	29.19	36.61	31.00	37.27	61.91	14.09	21.77	22.21	4.95	18.73	14.03
2008	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Rainfall mm	72.8	18.2	28.2									
Harvestable Rainfall m³	93.4	23.3	36.2									
Demand m³	16.95	25.48	15.47									

Table 3.3 Rainfall, harvestable rainfall and trough demand on farm between December 2006 – March 2008.

Table 5.5 shows monthly rainfall, harvestable rainfall and the demand for water supply to troughs on the farm. The demand for water exerted by the troughs in December 2006 was slightly greater than the volume of harvestable rainfall available. In 2007, monthly harvestable rainfall exceeded monthly demand except for March and April. Problems with filter efficiency resulted in pump downtime for June to November. A new filter regime was researched in this period and a replacement was installed in November. For the first three months of 2008 harvestable rainfall exceeded demand.

Demand for water at the cattle troughs peaked in December 2006 at 95m^3, during which time the farm had 170-180 cattle all housed indoors. Their drinking water supply was provided exclusively by the RWH system. Over 2007 the number of cattle on the farm was reduced, thus lowering water demand at the drinking troughs. In total the RWH system supplied 42.6% of the water used at the troughs connected to the RWH system on the farm between December 2006 and March 2008.

3.2.1 Discussion of Results

The RWH system over the monitored period supplied 42.6% of the demand for water at the farm troughs. This equates to a saving of 215m^3 of mains water, replaced by harvested rainwater for cattle drinking purposes on the farm. While this is a sustainable saving of water from the farmer's and supplier's point of view, it is not an economical one. At present the farmer is charged a fixed annual rate of €533.50 for water use on the farm. This is a flat fee. The local authority Meath County Council is in the process of installing meters so that all non-domestic consumers will be charged according to use. For consumers on metered supplies the current charge is €1.18 per m^3 for water, plus a meter rental charge of €34.10, with a minimum fixed charge of €199 per six months. If the farmer was on a metered supply his savings over the period would equate to €253.

One of the largest single costs in any RWH system is the storage tank. In this particular system two tanks were installed, a 9m^3 collection tank costing €1,500 and the 44m^3 storage tank costing €14,000. The savings in monetary terms made do not make installing a RWH system feasible at present. The farmer reduced his herd substantially during the monitored period decreasing demand thus the full potential for storage and rainwater use was decreased. The installation of a RWH facility on a dairy farm would be a more a sustainable application of the technology. Water use would more constant and financial savings would be significantly higher.

3.2.2 Conclusions

1. Over the monitoring period there was a 42.6% saving in mains water demand to supply cattle troughs. This equates to 215m^3 of mains water substituted by rainwater. This saving was made in spite of problems with the pump due to water quality issues during the period when commercial filters were not in place.

2. As in the domestic situation, savings made on water demand benefit the water producer, as the cost of RWH installation far outweighs the cost of the water to the farmer. From the producer's point of view, savings in water demand may mean a reduced need for developing new sources and/or increasing the capacity of existing treatment plants.

3.3 AGRICULTURAL HARVESTED RAINWATER QUALITY RESULTS

3.3.1 Testing Methodology

Samples were taken aseptically and transported to the laboratory within 4 hours and were stored between 2-8ºC in accordance with ISO/IEC 17025:2005 (ISO 17025, 2005). 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 as per Standard Methods (Standard Methods, 2005). 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) (No. 2) Regulations, S.I. No. 278 of 2007. However, the majority of these pollutants only arise in water treatment processes or when water is flowing through rock and soil. Although it was not necessary to monitor for all of these parameters, one full audit suite of testing was carried out.

3.3.2 Physico-chemical water quality (Regime 1)

Results for the harvested rainwater quality, Table 3.4, are compared with the European Communities (Drinking Water) (No. 2) Regulations, S.I. No. 278 of 2007 and the European Communities (Quality of Bathing Water) Regulations, S.I. 155 of 1992. No disinfection programme was carried out at any stage in the rainwater harvesting process. No first flush device was fitted to the system. It was considered an important function of the project to collect data on raw harvested rainwater [Pender et al., 2008; McIntyre et al., 2008].

Chloride demonstrated a mean of 3.83 mg/l with a minimum of 0 and a maximum of 27.83 mg/l. Nitrate as NO_3 had a mean of 1.23 mg/l with a minimum of 0 and a maximum of 2.84 mg/l while Nitrite as NO_2 showed a mean of 0.04 mg/l with a minimum of 0 and a maximum of 0.20 mg/l. The mean result for Sulphate was 3.35 mg/l with a minimum of 0 and a maximum of 37.40 mg/l. All of these parameters showed compliance with the Drinking Water Regulations.

The results achieved for pH showed a mean of 7.07 pH units with a minimum of 6.67 and a maximum of 7.83. Total dissolved solids demonstrated a mean of 59.15 mg/l with a minimum of 15 and a max of 174 mg/l. Suspended Solids had a mean of 5.23 mg/l, a minimum of 2 mg/l and a maximum of 22.00 mg/l. Turbidity showed a mean of 0.63 Nephelometric Turbidity Units (NTU) with a minimum of 0 and a max of 2.10 NTU. Sodium showed a mean of 2.62 mg/l, a minimum of 0 and a maximum of 16.40 mg/l, while Calcium had a mean of 5.43 mg/l, a minimum of 0 and a maximum of 46.80 mg/l. Cadmium showed a mean of 0 mg/l, with a minimum of 0 and a maximum of 0 mg/l. All of these parameters complied with the Drinking Water and Bathing Water Regulations.

Parameters	Units	Mean	Min	Max	SD	Median	Drinking Water Regs	Bathing Water Regs
Chloride	mg/l	3.83	0.00	27.83	7.37	1.49	250 mg/l	-
Nitrates NO_3	mg/l	1.23	0.00	2.84	0.92	1.20	50 mg/l	
Nitrite as NO_2	mg/l	0.04	0.00	0.20	0.06	0.03	0.50 mg/l	
Sulphate	mg/l	3.35	0.00	37.40	10.26	0.30	250mg/l	
Ammonia NH_3	mg/l	1.35	0.11	7.16	1.91	0.56	0.28 mg/l	
pH	pH Units	7.07	6.67	7.83	0.31	6.98	6.5 - 9.5	6.0-9.0
TDS	mg/l	59.15	15.00	174.00	48.75	49.00		
TSS	mg/l	5.23	2.00	22.00	5.82	3.00		
Turbidity	NTU	0.63	0.00	2.10	0.75	0.40	NAC&ATC*	
Sodium	mg/l	2.62	0.00	16.40	4.33	1.50	200 mg/l	
Calcium	mg/l	5.43	0.00	46.80	12.89	1.40	None	
Lead Total	µg/l	3.28	0.00	15.46	4.66	2.21	10 µg/l **	
Iron Total	µg/l	61.50	0.00	271.12	66.98	57.75	200 µg/l	
Cadmium Total	µg/l	0.00	0.00	0.00	0.00	0.00	5.0 µg/l	

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

Table 3.4 Overall Physico-chemical results for the harvested rainwater based on 19 monthly samples taken between January 2006 and July 2007.

Three chemical parameters tested did not comply with the Drinking Water Regulations; iron, lead and ammonia. Iron showed a mean of 61.50 mg/l with a minimum of 0 and a maximum of 271.12 mg/l. Lead had a mean of 3.28 µg/l with a minimum of 0 and a maximum of 15.46 µg/l. Ammonia, as NH_3, showed a mean value of 1.35 mg/l with a minimum of 0.11 mg/land a maximum of 7.16 mg/l. This parameter breached the drinking water standard of 0.28 mg/l on a number of occasions. There is no maximum value for ammonia, iron or lead stipulated in the Bathing Water Regulations.

3.3.3 Microbiological water quality (Regime 1)

Table 3.5 presents the bacteriological monitoring results for the agricultural rainwater harvesting facility over the 19 months sampling period between January 2006 and January 2007. These results exceeded both the Drinking Water and the Bathing Water Regulations. The results for Coliforms showed a maximum of 48,800 MPN/100ml, a minimum of 13.50 and a mean of 5,171.36 MPN/100ml. *E.coli* had a maximum of 2,419.6 MPN/100ml, a minimum of 0 and a mean of 259.62 MPN/100ml. Faecal coliforms showed a maximum of 600 cfu/100ml, a minimum of 0 and a mean of 83.92 MPN/100ml. Total viable count results at 22ºC showed a maximum value of 16,800 cfu/ml, a minimum of 0 and a mean 5291.90 cfu/ml and the maximum value achieved for TVC at 37ºC was 31500 cfu/ml, the minimum was 2 with a mean of 2,898.77 cfu/ml. Pseudomonas spp showed a maximum result of 299.00 cfu/100ml, a minimum of 0 and the mean was 62.25 cfu/ml.

Parameters	Units	Mean	Min	Max	SD	Median	Drinking Water Regs	Bathing Water Regs
Coliforms	MPN/100ml	5,171.36	13.50	48,800	13,241.35	920.80	0 no./100ml	5000/100ml
E coli	MPN/100ml	259.62	0.00	2,419.60	653.68	48.20	0 no./100ml	1000/100ml
Faecal Coliforms	-Cfu/100ml	83.92	0.00	600.00	160.35	30.00		1000/100ml
TVC @ 22ºC	Cfu/ml	5,291.90	0.00	16,800.00	5,513.60	3,684.00	NAC*	-
TVC @ 37ºC	Cfu/ml	2,898.77	2.00	31,500.00	8,615.99	431.00	NAC*	-
Pseudomonas spp	Cfu/100ml	62.25	0.00	299.00	86.68	33.00	0/100ml	

* NAC = No abnormal change

Table 3.5 Microbiological results for the harvested rainwater based on 19 monthly samples taken between January 2006 and July 2007.

3.3.4 Physico-chemical water quality (Regime 2)

Table 3.6 presents the Physico-chemical monitoring results for the agricultural rainwater harvesting facility over the 4 months sampling period between January 2008 and April 2008. Chloride demonstrated a mean of 9.94 mg/l, a minimum of 0 and a maximum of 18.75 mg/l. Nitrate, as NO_3, had a mean of 4.68 mg/l, a minimum of 1.77 and a maximum of 8.99 mg/l while Nitrite, as NO_2, showed a mean of 0.01 mg/l, a minimum of 0 and a maximum of 0.03 mg/l. The mean result for Sulphate was 3.40 mg/l with a minimum of 1.00 and a maximum of 7.30 mg/l. All of these parameters showed compliance with the Drinking Water Regulations. The results achieved for pH showed a mean of 6.33 pH units with a minimum of 5.69 and a maximum of 7.00. Total dissolved solids demonstrated a mean of 54.50 mg/l, with a minimum of 24.00 and a max of 84.00 mg/l. Suspended Solids had a mean of 3.25 mg/l, a minimum of 1 mg/l and a maximum of 5.00 mg/l.

Parameters	Units	Mean	Min	Max	SD	Median	Drinking Water Regs	Bathing Water Regs
Chloride	mg/l	6.94	0.00	18.75	8.16	4.51	250 mg/l	
Nitrates NO_3	mg/l	4.68	1.77	8.99	3.10	3.98	50 mg/l	
Nitrite as NO_2	mg/l	0.01	0.00	0.03	0.02	0.02	0.50 mg/l	
Sulphate	mg/l	11.11	0.63	41.58	20.32	1.11	250mg/l	
Ammonia NH_3	mg/l	1.35	0.11	7.16	1.91	0.56	0.28 mg/l	
pH	pH Units	6.33	5.69	7.00	0.56	6.32	6.5 - 9.5	6.0-9.0
TDS	mg/l	54.50	24.00	84.00	26.10	55.00		
TSS	mg/l	3.25	1.00	5.00	1.71	3.50		
Turbidity	NTU	1.82	0.37	4.30	1.72	1.31	NAC&ATC*	
Sodium	mg/l	5.46	0.09	13.69	5.84	4.03	200 mg/l	
Calcium	mg/l	10.40	3.90	22.90	8.91	7.40	None	
Lead Total	µg/l	5.32	2.63	8.16	2.34	5.24	10 µg/l **	
Iron Total	µg/l	59.75	20.80	105.00	38.23	56.59	200 µg/l	
Cadmium Total	µg/l	0.30	0.20	0.40	0.12	0.30	5.0 µg/l	

* No abnormal change and acceptable to consumers

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

Table 3.6 Overall Physico-chemical results for the harvested rainwater based on 4 monthly samples taken between January 2008 and April 2008.

Turbidity showed a mean of 1.82 Nephelometric Turbidity Units (NTU), with a minimum of 0.37 and a max of 4.30 NTU. Sodium showed a mean of 5.46 mg/l, a minimum of 0.09 and a maximum of 13.69 mg/l, while Calcium had a mean of 10.40 mg/l, a minimum of 3.90 and a maximum of 22.90 mg/l. Cadmium showed a mean of 0.30 mg/l with a minimum of 0.20 and a maximum of 0.40 mg/l. Iron showed a mean of 59.75 mg/l with a minimum of 20.80 and a maximum of 105.00 mg/l while Lead had a mean of 5.32 µg/l with a minimum of 2.63 and a maximum of 8.16 µg/l. All of these parameters complied with the Drinking Water and Bathing Water Regulations.

One chemical parameter tested did not comply with the Drinking Water Regulations, and that was Ammonia. Ammonia as NH_3, showed a mean value of 11.11 mg/l with a minimum of 0.63 mg/l and a maximum of 41.58 mg/l. This parameter breached the drinking water standard of 0.28 mg/l on the 4 monthly samples. There is no maximum value for Ammonia stipulated in the Bathing Water Regulations.

3.3.5 Microbiological water quality (Regime 2)

Table 3.7 presents the bacteriological monitoring results for the agricultural rainwater harvesting facility over the 4 months sampling period between January 2008 and April 2008. These results exceeded only the Drinking Water and not the Bathing Water Regulations. The results for Coliforms showed a maximum of 275.50 MPN/100ml, a minimum of 3.10 and a mean of 73.93 MPN/100ml. *E.coli* had a maximum of 2.00 MPN/100ml, a minimum of 0 and a mean of 0.75 MPN/100ml. Faecal coliforms showed a maximum of 5 cfu/100ml, a minimum of 0 and a mean of 1.50 cfu/100ml. Total viable count results at 22ºC showed a maximum value of 800 cfu/ml, a minimum of 50 and a mean 364.25 cfu/ml. The maximum value achieved for TVC at 37ºC was 140 cfu/ml, the minimum was 31 with a mean of 62.25 cfu/ml. Pseudomonas spp showed a maximum result of 2000 cfu/100ml, a minimum of 27 and the mean was 556.75 cfu/ml.

Parameters	Units	Mean	Min	Max	SD	Median	Drinking Water Regs	Bathing Water Regs
Coliforms	MPN/100ml	73.93	3.10	275.50	134.41	8.55	0 no./100ml	5000/100ml
E coli	MPN/100ml	0.75	0	2.00	0.96	1.00	0 no./100ml	1000/100ml
Faecal Coliforms	-Cfu/100ml	1.50	0	5.00	2.38	1.0		1000/100ml
TVC @ 22ºC	Cfu/ml	364.25	50.00	800.00	345.60	303.50	NAC*	-
TVC @ 37 ºC	Cfu/ml	62.25	31.00	140.00	52.20	39.00	NAC*	-
Pseudomonas spp	Cfu/100ml	556.75	27.00	2,000.00	962.78	100.00	0/100ml	-
* NAC = No abnormal change								

Table 3.7 Microbiological results for the harvested rainwater based on monthly samples taken between January 2008 and April 2008.

3.3.6 Discussion of results

Regime 1: All results were obtained without any form of disinfection or the use of a first flush device. The microbiological results show that there is a major and consistent problem with the microbiological quality of the water. The levels of coliforms found in the water here are in breach of the Bathing Water regulations. The numbers of coliforms peaked twice at approximately 3,500 MPN/100ml and at no stage was this system free from coliforms. *E. coli* and faecal coliforms were also detected in each sample taken. The numbers detected were significant. The parametric value for each of the faecal indicator organisms in drinking water is zero, meaning that some form of disinfection would have to be carried out if this water was to be considered suitable for human consumption.

As faecal indicator organisms were present in each of the samples, pollution of faecal origin has occurred, but the fact that *E.coli* is present shows that the pollution was heavy and recent. If coliforms are detected in the absence of *E. coli* the inference is that the pollution is either recent and non-faecal in origin or is of remote faecal origin such that the intestinal coliforms have not survived (Environmental Protection Agency, 2001). The most likely source of this contamination was waste from the cattle being washed in to the rainwater system. There were a number of downpipes channelling rainwater from the roof into the underground storage tank. The AJs at the bottom of these downpipes were not sealed after installation, thus allowing any heavy falls of rain to wash animal waste and debris from the farmyard into the collection tank.

As was the case in Carlow, the tanks were left open for some time after installation before being put into operation (Ó hÓgáin et al, 2008). This would have allowed for significant contamination to occur. The system was not flushed out or chlorinated before use, meaning that there was no chance to remove any of this built up debris. The fact that contamination from the farmyard occurred underlines the importance of sealing the AJs at the bottom of the downpipes.

The Physico-Chemical results for Regime 1 were compliant with the Drinking Water Regulations, with the exception of one parameter. This shows that even under inefficient rainwater collection installations, the non-microbiological quality of the water is of a good standard. The parameter that breached the regulations was Ammonia, as NH3. This confirms the observations made in relation to the microbiological results, as ammonia is also an indicator of faecal contamination. The significance of high levels of ammonia is that they interfere with chlorination processes in water treatment by the formation of chloramines which are much less potent disinfectants than free chlorine (Environmental Protection Agency, 2001). The presence of cattle and their waste is ubiquitous in a farming context and, therefore, Ammonia values are problematical when collecting rainwater on a farm. Sealing of the Armstong Junctions, while likely to reduce Ammonia in the harvested rainwater, is unlikely to eliminate it altogether, as the parameter will be present in the atmosphere surrounding intensive cattle-rearing operations.

Regime 2: Extensive work was carried out to the rainwater drainage network during August-October 2007. This included the fitting of coarse and fine mesh filters to all downpipes, while all manholes were sealed to eliminate potential contamination of the rainwater supply by the ingress of farmyard effluent. The collection tank was also cleaned out on two occasions. With the completion of the new installation, sampling resumed in January 2008. The quality of the harvested rainwater for this period shows compliance with the Bathing Water Regulations for all parameters. With the exception of three parameters, two microbiological and one Physico-chemical, the Drinking Water Regulations were achieved. These parameters were Nitrate as Ammonia, Coliforms and *E.Coli*. The continuing high value for Ammonia in the harvested water, despite the sealing of the AJs, may be a feature of the agricultural environment. The presence of Coliforms and *E.coli* are probably also a feature of this. The inclusion of a filter and sealing of the AJs removed a large volume of debris but the continued presence of high levels of Ammonia and Coliforms and *E.coli* indicated that disinfection would be required. Filtration on its own does not remove all of the bacteria present in this environment. However, the reduction in the values of these parameters is marked and shows the importance of sealing all downpipes. The new commercially available filters performed to a higher standard than the home-made variety installed in Regime 1.

3.3.7 Conclusions

1. The Rainwater harvesting installation set up in Clonalvy, County Meath, referred to as Regime 2 (consisting of two commercially available downpipe filters and accompanied by the sealing of all downpipe AJs), harvested rainwater that complied with the Bathing Water Regulations.

2. The physico-chemical results from the site in Clonalvy, County Meath, Regime 1, complied with the Drinking Water Standards over the sampling period, except for the Ammonia parameter. Microbiological results breached both the drinking and bathing water standards on all sampling dates.

3. The results from the agricultural site show the importance of the installation and its components. The use of non proprietary filters and the fact that the downpipes were not sealed reinforced the importance of proper installation.

4. THERMAL DESTRUCTION ANALYSIS OF WATER RELATED PATHOGENS AT DOMESTIC HOT WATER SYSTEM TEMPERATURES

4.1 INTRODUCTION.

Health concerns over bacterial contamination of hot water systems have hindered the widespread recommendation of rainwater use in hot water systems, where an alternative mains water supply exists. In Ireland, the absence of any detailed National Standards for installation and use of rainwater harvesting has limited usage to toilet flushing and outdoor taps. The principal fear concerns the ability of hot water systems to produce water of sufficient quality for human use. 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 domestic hot water system temperatures. This aspect of the project was designed to establish scientific data that will facilitate reasoned debate and enable the establishment of National Standards for use of Rainwater Harvesting for domestic hot water systems.

Health concerns over hot water systems have resulted primarily from the bacteria Legionella pneumophila. L. pneumophila is the agent of Legionnaires disease, an acute form of pneumonia, which most commonly infects the respiratory tract of immuno-compromised individuals. L. pneumophila associated infections occur as a result of the inhalation of contaminated aerosols. Ingestion of high concentrations of L. pneumophila does not cause harm. A limited amount of research has been conducted in relation to the heat tolerance of L. pneumophila in a water medium As a result of this research, standards have been developed that state that hot water systems should be maintained above 60°C in order to inhibit the growth of L. pneumophila (CIBSE,1999). The storage water temperature should not exceed 65°C (CIBSE, 1999).

While extensive research has been undertaken in the food industry to determine heat inactivation rates for pathogens, little data exists for thermal inactivation in a freshwater medium. Past sterilisation practices have focused on temperatures exceeding 100°C, ranges which naturally targeted the most heat resistant spore forming bacteria, very few of which are relevant to water, and have neglected developing heat death rate data for species in lower temperature ranges. Research is also lacking in the water industry, as heat disinfection has never been economically feasible. During water contamination alerts, the public are generally advised to boil the water for 10 minutes, although this is far in excess of the heat required to destroy non-spore-forming bacterial cells.

4.2 TESTING METHODOLOGY

The bacterial species used in this experiment 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 sterile phosphate buffer solution. These were chosen as they were the bacteria analysed in the pilot project (Ó hÓgain et al., 2008). 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.

Thermal inactivation data for the range of bacteria relevant to health in hot water systems is rare, although extensive work has been carried out in Australia in the last number of years. The aim of the thermal experiments was to determine the time required to reduce a bacterial population by 100% or 1 log reduction, for the potential waterborne pathogens mentioned, in a water medium at temperatures relevant for domestic hot water systems.

4.3 RESULTS

Two sets of experiments were carried out, one set at 55ºC and the other at 60ºC. The purpose of this was to investigate the correlation of reduction rate and temperature.

Parameters	Units	0 minutes	5 minutes	10 minutes	15 minutes	20 minutes
Coliforms	MPN/100ml	248.3	2.1	0	0	0
E coli	MPN/100ml	248.3	2.1	0	0	0
TVC @ 22ºC	Cfu/ml	88	0	0	0	0
TVC @ 37 ºC	Cfu/ml	101	0	0	0	0
Pseudomonas spp	Cfu/100ml	12	0	0	0	0
Faecal Coliforms	Cfu/100ml	36	0	0	0	0

Table 4.1 Microbiological results for heat treatment experiments carried out at 55^{0}C.

Table 4.1 shows the microbiological results for Coliforms, *E. coli*, Faecal Coliforms, Salmonella, Pseudomonas aeruginosa and TVC (at 22ºC and 37ºC). All water samples incubated at 55ºC for 5, 10, 15 and 20 minutes respectively. Values for Coliforms and *E. coli* were highest at Time 0, as would be expected. The sample was taken prior to heat treatment at 55ºC. Both the Colifom and *E. coli* results were the same at 248.3 MPN/100ml. After 5 minutes at 55ºC, values showed a marked decrease to 2.1 MPN/100ml. At all other times, 10, 15 and 20 minutes respectively, no Coliforms nor *E. coli* were detected in the samples (Fig. 4.1). TVC at 22 and 37ºC were also highest at Time 0, 88 cfu/ml at 22ºC and 101cfu/ml at 37ºC. After 5 minutes no TVC at 22 or 37ºC were detected and none at Time 10, 15 or 20 minutes (Fig. 4.2).

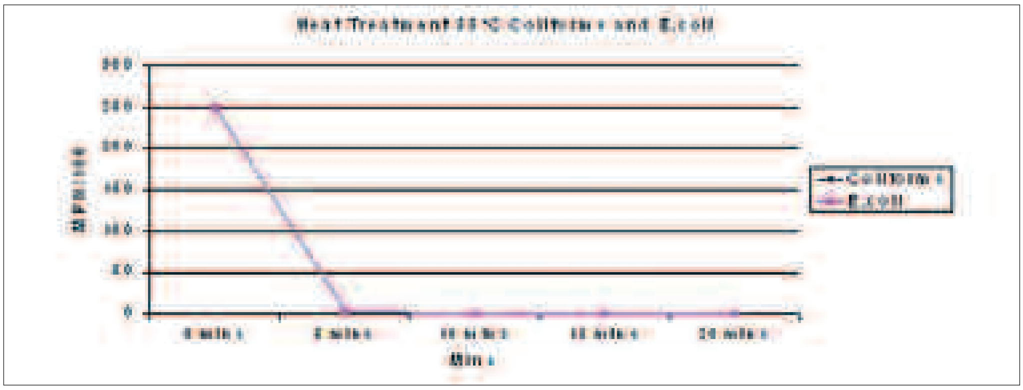


Fig. 4.1 Coliform and E.coli results for Heat Treatment Experiments at 55ºC.

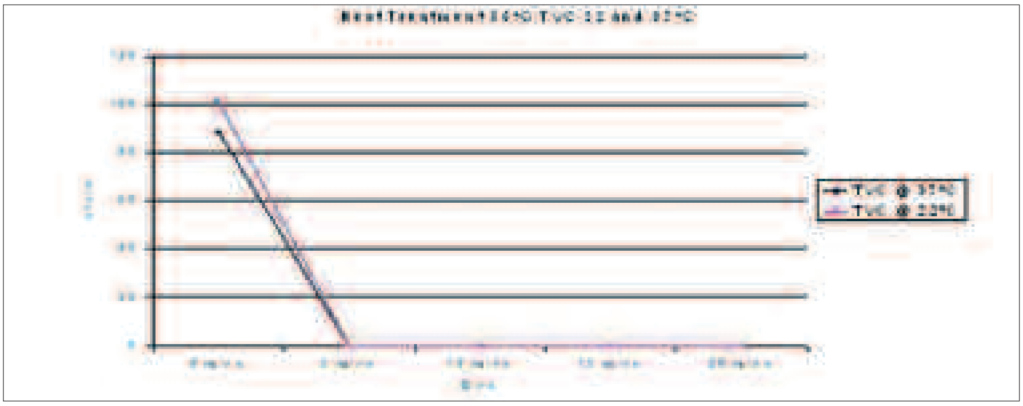


Fig. 4.2 TVC @ 22 and 37ºC results for Heat Treatment Experiments at 55ºC.

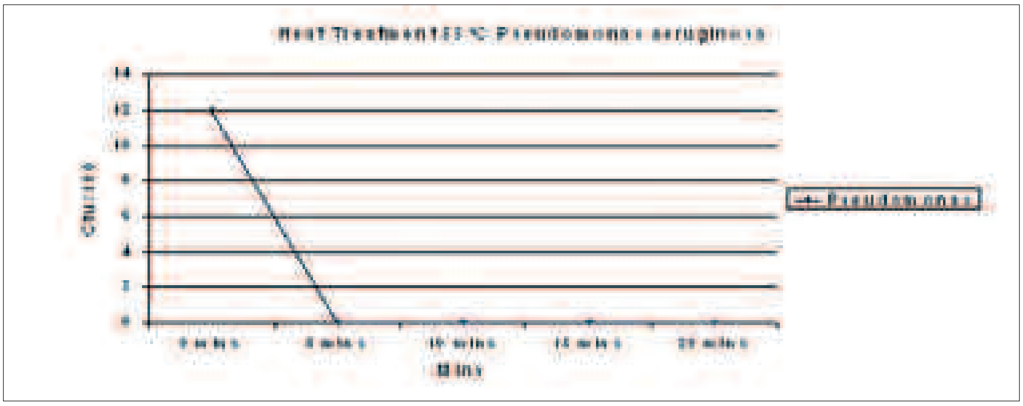


Fig. 4.3 Pseuodomonas aeruginosa results for Heat Treatment Experiments at 55ºC.

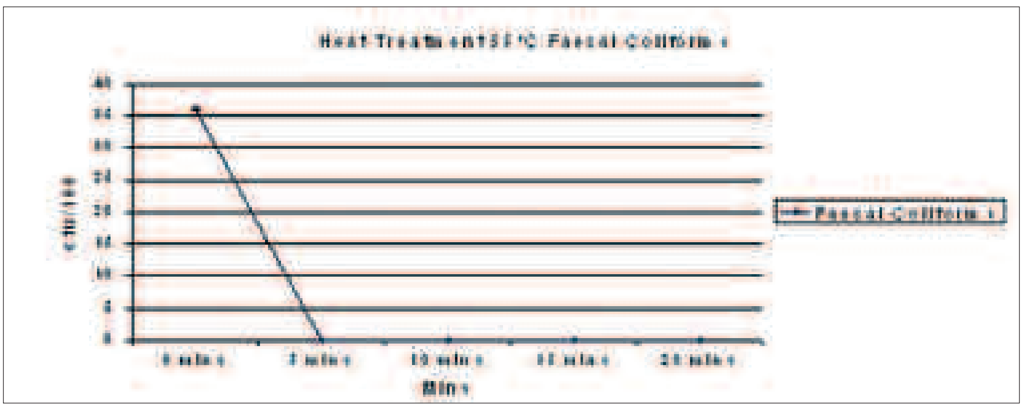


Fig. 4.4 Faecal Coliforms results for Heat Treatment Experiments at 55ºC.

Pseudomonas aeruginosa (12 cfu/100ml) was detected at Time 0 minutes. As with TVCs, no Pseudomomas aeruginosa was detected at 5, 10, 15 or 20 minutes (Fig.4.3). Faecal Coliforms (36 cfu/100ml) were detected at Time 0 minutes. After incubation, no Faecal Coliforms were detected at 5, 10, 15 or 20 minutes (Fig.4.4).

Time (mins)	Result
0	Detected
5	Not Detected
10	Not Detected
10	Not Detected
10	Not Detected

Table 4.2 Salmonella results for Heat Treatment Experiments at 55⁰C.

Table 4.2 shows the results for Salmonella isolation at heat treatment experiments conducted at 55ºC. Salmonella was detected at Time 0, but was absent in all samples at 5, 10, 15 and 20 minutes.

4.3.1 60⁰ Heat treatment Experiments

Table 4.3 shows the microbiological results for Coliforms, *E. coli*, Faecal Coliforms, Salmonella, Pseudomonas aeruginosa and TVC at 22ºC and 37ºC. All water samples incubated at 60ºC for 5, 10, 15 and 20 minutes respectively.

Parameters	Units	0 minutes	5 minutes	10 minutes	15 minutes	20 minutes
Coliforms	MPN/100ml	261.3	0	0	0	0
E coli	MPN/100ml	261.3	0	0	0	0
TVC @ 22ºC	Cfu/ml	90	0	0	0	0
TVC @ 37 ºC	Cfu/ml	129	0	0	0	0
Pseudomonas spp	Cfu/100ml	15	0	0	0	0
Faecal Coliforms	Cfu/100ml	34	0	0	0	0

Table 4.3 Microbiological results for heat treatment experiments carried out at 60⁰C.

Coliforms and E.coli were highest at Time 0, as would be expected. This sample was taken prior to heat treatment at 60ºC. Both the Colifom and *E. coli* results were the same at 261.3 MPN/100ml. After 5 minutes at 60ºC no coliforms nor *E. coli* were detected. This was also seen at times 10, 15 and 20 minutes (Fig. 4.5). TVC at 22 and 37ºC were also highest at Time 0, 90 cfu/ml at 22ºC and 129cfu/ml at 37ºC. After 5 minutes no TVC at 22 or 37ºC were detected and none at Time 10, 15 or 20 minutes (Fig.7.6). Pseudomonas aeruginosa was detected at Time 0. 15 cfu/100ml was detected. Similarly to TVC's and Faecal Coliforms, no Pseudomonas aeruginosa was detected at 5, 10, 15 or 20 minutes (Fig. 7.7).

Faecal Coliforms were also detected at Time 0. 34 cfu/100ml was detected. Similarly to TVC's and Pseudomonas spp, no Faecal Coliforms was detected at 5, 10, 15 or 20 minutes (Fig. 7.8).

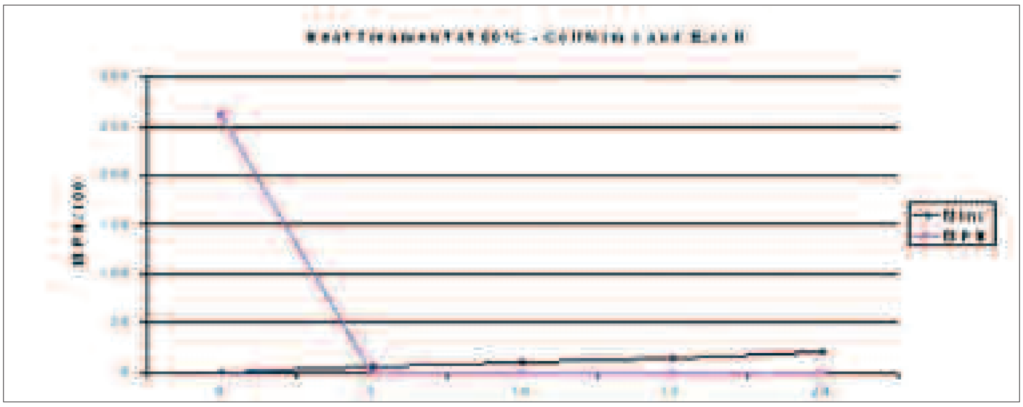


Fig. 4.5 Coliform and *E. coli* results for Heat Treatment Experiments at 60ºC.

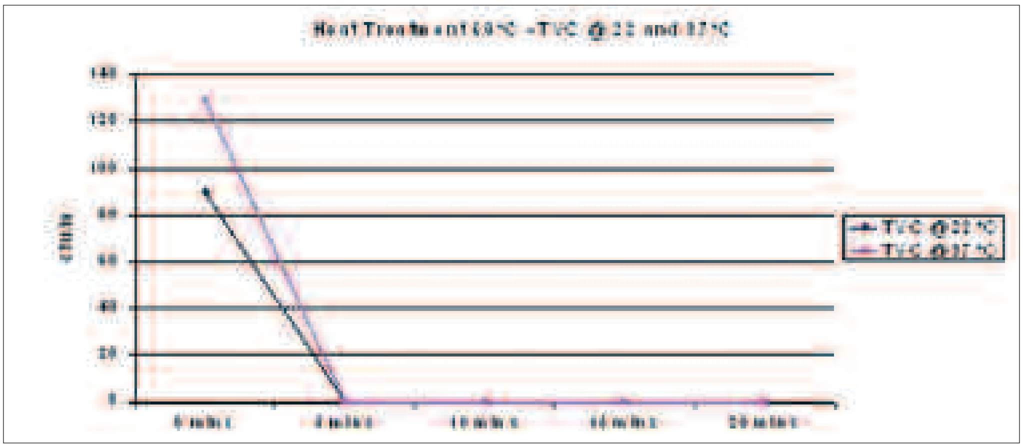


Fig. 4.6 Coliform TVC @ 22 and 37ºC results for Heat Treatment Experiments at 60ºC.

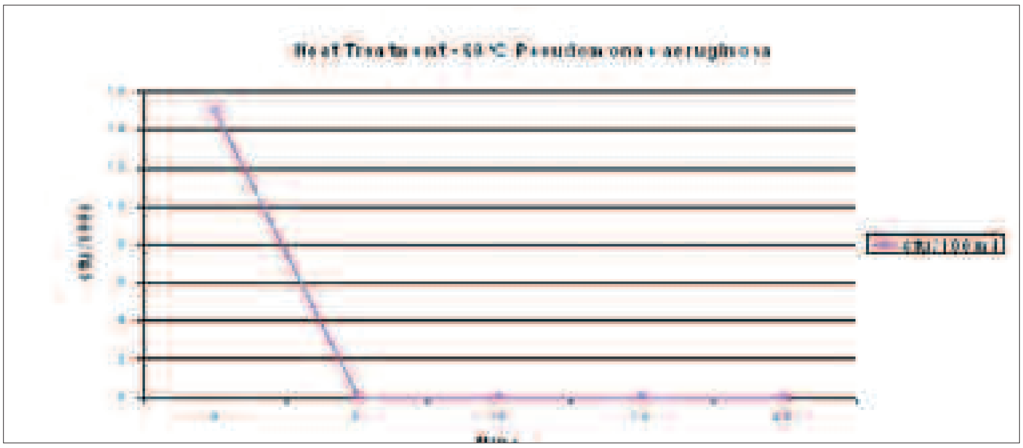


Fig. 4.7 Pseudomonas aeruginosa results for Heat Treatment Experiments at 60ºC.

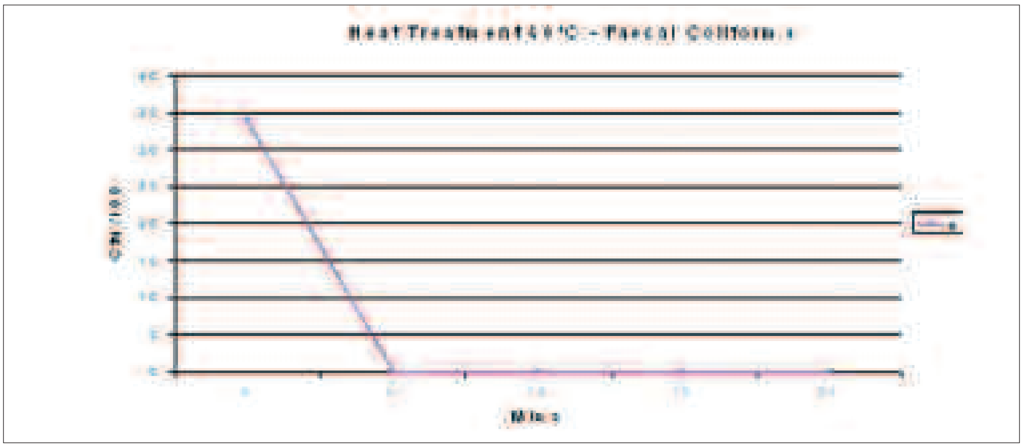


Fig. 4.8 Faecal Coliform results for Heat Treatment Experiments at 60ºC.

Table 4.4 shows the results for Salmonella isolation at heat treatment experiments conducted at 60ºC. Salmonella was detected at Time 0 but was absent in all samples at 5, 10, 15 and 20 minutes.

Time (mins)	Result
0	Detected
5	Not Detected
10	Not Detected
10	Not Detected
10	Not Detected

Table 7.4 Salmonella results for Heat Treatment Experiments at 60ºC.

4.4 DISCUSSION OF RESULTS

The study showed that hot water systems maintained at adequately high temperatures reduces the bacterial load to zero. The mechanism of cell inactivation and destruction of cells would appear to be through the loss of essential cell components, brought about by the breakage of bonds due to excessive energy. The abnormal folding or unfolding of proteins and the loss of cell membrane cohesion, resulting in breakdown of cross-membrane transport, are two common pathways by which the integrity of a cell can be lost. The proportion of cells being reduced will be approximately constant while this single factor (heat) is responsible for inactivation.

The 55°C results show that reduction in bacterial load is not as rapid for Coliforms and *E. coli* as at 60°C, and that 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. These results are comparable with results from international studies reported on similar experiments (Spinks et.al, 2003). The results of that study showed that water related bacteria rapidly die off in temperatures relevant for domestic hot water systems. The D-values, defined as the time required to reduce a bacterial population by 90% or 1 log reduction, at 65°C and 60°C for *E. coli* were 3secs and 62secs respectively, while at 55°C *E. coli* displayed an initial D-value of 21mins followed by 4mins. For Pseudomonas aeruginosa, the D-values at 65°C, 60°C, and 55°C were 5secs, 49secs, and 5mins, for Salmonella typhimurium, <2secs, 4secs, and 77secs, and for Klebsiella pneumoniae, <2secs, <2secs, and 35secs, respectively. The results indicate that after fifteen minutes at 60°C, *E. coli* concentrations will have been reduced by 15-log reductions, while the other pathogens experienced similar or even greater reductions.

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.

The results of this pilot study indicate that after five minutes at 60°C, *E. coli*, P. aeruginosa, S. typhimurium and S. typhimurium concentrations will have been reduced to zero. At 55°C, inactivation rates are much slower for *E. coli* and P. aeruginosa, but are still rapid for S. typhimurium. Hot water systems maintained at 55°C for 30 minutes would provide water relatively free of the above mentioned bacteria. At 65°C destruction of bacteria would be almost instantaneous.

Human pathogens are restricted to temperature ranges around 37°C. Enterohemorrhagic Escherichia coli (EHEC) has a growth range between 8 and 48°C, and Aeromonas spp. between 4-45°C [Szewzyk et al, 2000]. At temperatures exceeding maximum growth limits, thermal death rates are high, such as for Campylobacter sp. that survive for only a few hours at temperatures exceeding their optimal 37°C range [Szewzyk et al, 2000]. As well as studying Legionella species, Stout et al [1986] also investigated the D-values for species from other genera. At 60°C, 70°C, and 80°C, Pseudomonas aeruginosa had D-values of 2.6, 1.3 and 0.7 respectively. Staphylococcus aureus had D-values of 2.6, 1.3 and 0.5 mins, while Tatlockia micdadei 4.5-10.6, 1.1-2.5, and 0.5-0.7 mins at 60°C, 70°C, and 80°C respectively [Stout et al., 1986]. The concern of bacteria hiding in biofilms in hot water systems maintained at adequate temperatures is also somewhat unfounded, as Keevil et al. [1995] noted the lack of biofilm development in water tanks maintained above 60ºC in their review.

The utilisation of harvested rainwater for domestic hot water use is a safe alternative to mains water. It is also a sustainable use of the harvested rainwater and has the potential to reduce mains use by up to 80%.

5: ECONOMIC ANALYSIS OF RAINWATER USE

A full cost benefit economic analysis which assesses the cost implications of installing rainwater harvesting facilities compared with the reduced capital, operational & maintenance costs for headworks, water supply network and wastewater treatment and collection network is outside the scope of this pilot study. In this chapter the payback period to the consumer resulting from the installation of a domestic rainwater harvesting system is presented. A further in-depth economic assessment is required to calculate the inherent cost benefits to the water producer and waste water treatment operator.

Introduction: Rural Group Water Supply in Ireland

In rural Ireland, networked water supplies are provided either by local authoritites directly, by group water schemes (GWS) that receive their supplies from a local authority at a bulk meter, or by privately-sourced group water schemes that abstract, treat and distribute their own supplies. Current Irish government policy requires that local authorities should apply charges to the non-domestic sector that reflect the costs (both capital and operational) of provision of water and wastewater services. These charges are applied on the basis of a unit charge in respect of metered water supply and/or a flat rate charge per annum. The domestic consumer is not charged on a local authority network. By contrast, both domestic and non-domestic consumers on a GWS are subject to charges. Each group water scheme determines its own charging policy, but the trend is towards charging on metered usage, particularly for those schemes that have entered into 20-year Operate & Maintenance contracts for their water treatment.

5.1 COST BENEFIT ANALYSIS OF RAINWATER HARVESTING

The economic benefit of reduced water demand can be assessed using various models. At the most basic level, the cost of the water saved over the lifetime of RWH can be compared with the initial capital costs of installation and recurring operational & maintenance cost. However, there are additional cost benefits both to the consumer and producer/supplier, but these are more difficult to accurately quantify.

5.1.1 Cost benefits to the producer/supplier

In terms of developing water resources to meet the increased demands of the domestic and non domestic sectors, the least cost option may be to utilise water conservation strategies to generate additional supply. The additional savings from the reduced wastewater volume may be significant also, as the full costs of increasing capacity to collect and treat wastewater are increasing faster than the costs of supplying more water. In an area where future anticipated demand is greater than the available supply, the production of new water by reducing the per capita demand and thereby mobilising new supply may be the least cost option, particularly when the environmental and social costs of developing new resources are included in the analysis. Studies in Australia (Coombes, 2003) have shown that while a cost analysis of water conservation measures (which assesses the economic benefit of water savings only), may indicate payback periods of greater than 10 years, when the additional savings that will accrue from such strategies are included, the results show a highly favourable benefit-cost ratio to both the consumer, producer and society as a whole.

5.1.2 Cost benefits to the Consumer

To promote and encourage householders to invest in this technology will require incentives to be introduced. At present domestic consumers on public mains do not pay any fees for their water use, while those connected to group water schemes are charged for water. To investigate what would be required to make installing a RWH system financially viable, two parameters were taken; water charges and payment of an installation grant.

5.1.3 Water Charges

The water charges taken were the average (€1.00) and highest charge (€2.43) levied on non-domestic consumers per m^3 in 2006, as published by Chambers Ireland. A maximum projected water supply charge of €3.00 per m^3 was included in the analysis to give an indication of future potential demand for RWH. The costs associated with installing two RWH systems incorporating different size collection tanks are given in Table 5.1. A system designed to supply all non-potable household water use with a 30-day dry storage reserve requires a $9m^3$ storage tank. If rainwater supply is utilised only for toilet flushing, with a minimum 5-day dry storage, a $2m^3$ tank is sufficient in the Irish climate. The RWH with a $9m^3$ tank is 30% more expensive, with increased excavation and tank supply cost.

To evaluate the financial attractiveness of installing an RWH system to the householder, a simplified CAPEX financial evaluation model was used. This model was adapted to the rainwater harvesting installation. A simplified analysis was carried out with the payback taken as the time (years) for the cumulative cash flow to become positive, taking into account capital investment less ongoing yearly charges. The parameters used in setting up the model were, a PCC value of 157 litres per head per day. This is the highest PCC reading of the four houses in the study. A 30% replacement of mains water by rainwater was chosen. The cost of capital was set at 5%. Pump replacement costs were estimated at €300 every 5 years.

Rainwater installation	Item	9m^3 tank	2m^3 tank
		€	€
	Fittings	2,012.55	2,012.55
	Precast Reinforced Concrete Tank	1,500.00	650.00
	Installation Costs	840.00	525.00
	Total Capital Costs	€4,353	€3,188

Table 5.1 Installation costs of a domestic RWH system.

5.2 RESULTS

Assumptions :

- Household water use = PCC 157 l per hd-d
- Harvested Rainwater Supply = 30% PPC

Grant (based on % of capital costs)	Main Water Charge per 1,000 litres (m^3)		
	€1.00	€2.43	€3.00
	Estimated Payback Period (years)		
	(yrs)	(yrs)	(yrs)
50%	-	23.5	16
75%	-	9	6.6
80%	-	7	5
95%	13.5	1	0.7

Table 5.2 Estimated cost benefit for RWH Facility with 2m^3 storage tank.

Grant (based on % of capital costs)	Main Water Charge per 1,000 litres (m^3)		
	€1.00	€2.43	€3.00
	Estimated Payback Period (years)		
	(yrs)	(yrs)	(yrs)
50%	-	-	29
75%	-	22.5	12
80%	-	16.5	2
95%	-	2	1

Table 5.3 Estimated cost benefit for RWH Facility with 9m^3 storage tank.

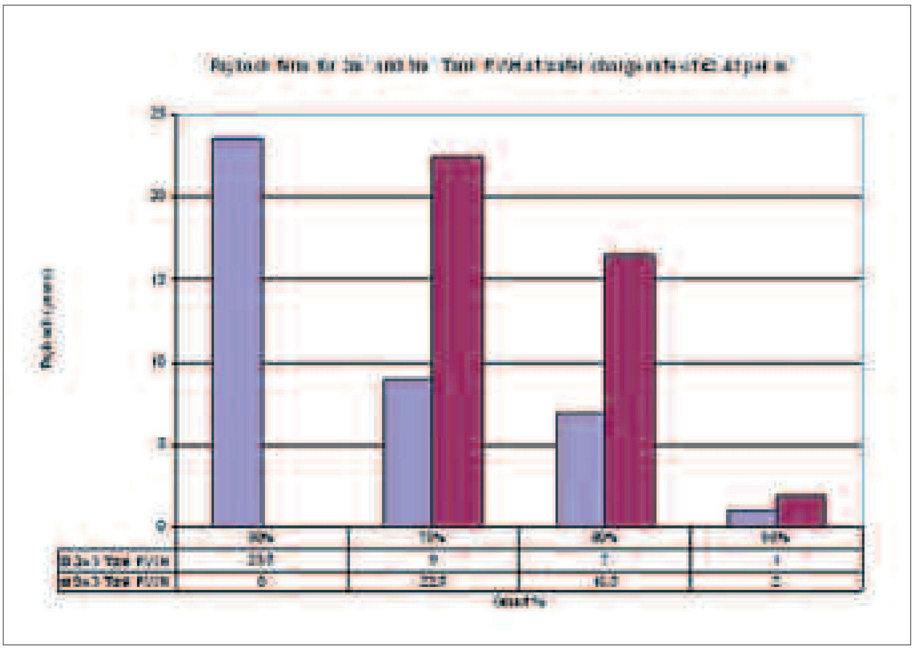


Fig. 5.1 Payback period for 2m^3 and 9m^3 RWH system with water charges at €2.43 per m^3.

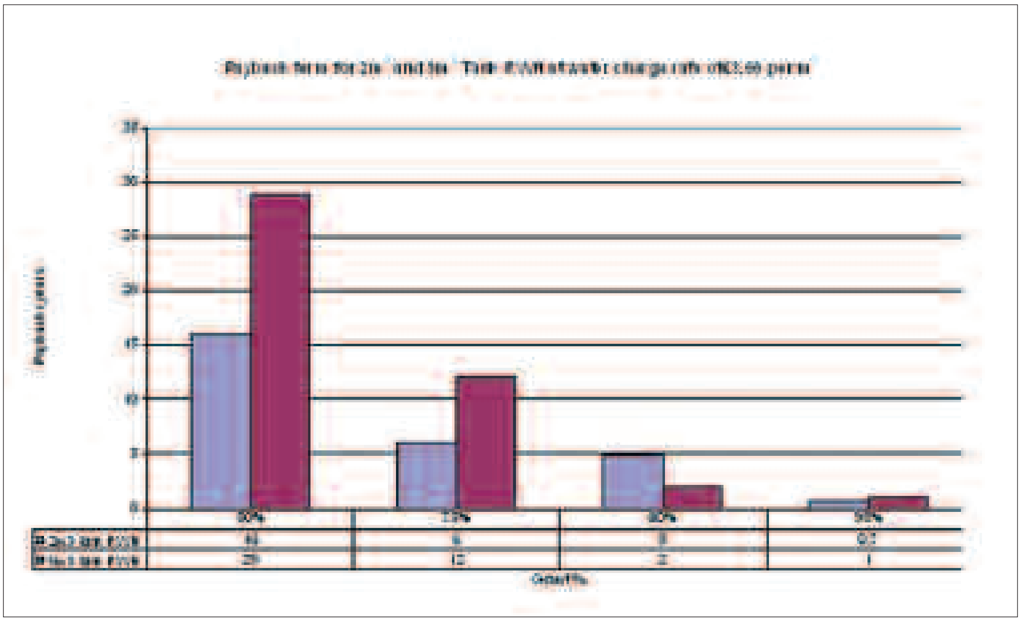


Fig. 5.2 Payback period for 2m³ and 9m³ RWH system with water charges at €3.00 per m³.

5.3 DISCUSSION OF RESULTS

Two systems were assessed, facilities with a 2m³ and 9m³ storage tank respectively. The actual pilot RWH installation used a 9m³ storage tank. The financial analysis for this facility indicates that if the consumer received a capital grant of 50% towards the cost of installation and purchase, a water charge rate of €1.00 or €2.43 per m³ would not yield any financial return to the consumer, ie. there would no payback. If the water charge increased to €3.00 per m³, it would take 29 years to achieve a payback. At a water charge of €1.00 per m³ the level of grant is not significant for the consumer to make an economic-based decision to install an RWH system. Capital Grants at 75%, 80% and 95% similarly do not lead to any payback period, so the installation is uneconomic at this level of water charges.

There is an inverse relationship between water charges and the grant required to make RWH financially attractive to householders. The lower the charge applied to water per m³ the higher the grant that is required to make the RWH financially attractive. The higher the grant available the lower the water charge at which the RWH is financially attractive to householders. Thus, at 75% grant-aid, water charges at €2.43 and €3.00 per m³ give a payback term of 22.5 and 12 years respectively. At 80% grant aid rate, the same water charges gives payback periods of 16 and 2 years respectively. At 95% grant aid, payback could be achieved in a period of 2 years and 1 year respectively.

5.4 CONCLUSIONS

With the present level of water charges in Ireland (and in the absence of comparative analysis of economic externalities such as environmental and social consequences of traditional water supply and storm water disposal networks), there is no economic basis for a consumer to justify the costs of installation and operation of a rainwater harvesting facility. Any decision to install is based on environmental awareness. Cost savings to the supplier have not been assessed in this study.

With increased levels of water charges the economic justification becomes more attractive to the consumer. The conclusion is that for rainwater harvesting to make financial sense for the consumer some significant level of capital grant aid must be provided. This is in line with other European countries such as Germany which gives a reduction in water charges based on roof size for houses with rainwater harvesting facilities.

If policies are adopted to encourage the widespread installation of rainwater harvesting in domestic dwellings and many such projects are completed, then potentially there are substantial urban infrastructure cost savings to the developer and local authority respectively.

If a Local Authority responsible for delivery of local water supply and provision of storm water runoff networks has reached the stage of full utilisation of its infrastructure and is faced with the decision to expand its reservoir, water distribution system, wastewater treatment and storm water infrastructure to meet the needs of extra population, then a comparison should be made between:

- the life cycle cost of new and existing infrastructure required to satisfy the (conventional) additional water supply demand and storm water load.
- the lifecycle cost of new SUDS practices (including rainwater harvesting)which decrease water consumption and storm water load and hence defer the need for new infrastructure.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

The conclusions may be divided into three sections, those regarding rainwater harvesting in general, those from the domestic project and those from the agrictural project.

6.1.1. General

1. Rainwater harvesting is a sustainable water conservation measure.
2. Harvested rainwater is an underused source of raw water and its use has the potential to contribute to the sustainability of raw water sources of supply and to the long term viability of water treatment plants.
3. Harvested rainwater has the potential to supplement sources of water supply for non-potable uses.
4. The design and installation of a rainwater harvesting system should be undertaken by competent/specialist trained personnel.
5. Ongoing maintenance of a rainwater harvesting system is required to ensure optimum performance.
6. Current water charging policies act as a disincentive to the installation of rainwater harvesting systems.
7. The introduction of a significant level of grant aid would, therefore, be required in order to have rainwater harvesting considered a financially viable option.
8. The provision and siting of storage for harvested rainwater will depend on site restrictions and capacity needs.
9. The utilisation of harvested rainwater for domestic hot water use could, under appropriate conditions, be considered as a safe and sustainable alternative supply to mains water, with a possible reduction in demand of up to 80%.
10. The potential benefits of rainwater harvesting are not widely appreciated by the public at large or by those involved in building design and construction.

6.1.2. Domestic Project

1. Harvested rainwater provided sufficient water to replace all mains water used for toilet-flushing in the house for the duration of the project.
2. The harvested rainwater was sufficient to supply approximately 40% of water demand in the control houses.
3. Water quality consistently met the Bathing Water Regulations.
4. In 37% of the samples taken, harvested rainwater quality complied with the Drinking Water Regulations.
5. Non-compliance with the Lead parameter was attributed to the use of lead flashings on the roof.
6. Grant aid may act as an incentive for the installion of RWH systems.
7. Site limitations, the capacity of the collection tank and the associated costs are factors for consideration in deciding on the rainwater harvesting system to be installed and the components of water usage that are to be substituted by the system.
8. The principal beneficiary of a rainwater harvesting system in a domestic situation is the water producer.
9. Experimental work showed that a domestic hot water system, with a temperature of 60°C, will disinfect harvested rainwater and kill all pathogens. This could, in the appropriate circumstances, allow harvested rainwater to be used for other domestic applications.
10. A simple and effective maintenance programme is required for RWH systems. They are not fit-and-forget.

6.1.3 Agricultural Project

1. The rainwater harvesting system supplied 43% of the livestock water demand on the farm.
2. The system used on the agricultural project is replicable and may be used for dairy farms and other agricultural applications.

3. With the exception of the Ammonia parameter, the physico-chemical results showed compliance with the Drinking Water Standards.
4. Compliance with the Bathing Water Regulations was achieved after the installation of commercially-made filters.
5. The microbiological results breached both the Drinking and Bathing Water Regulations.
6. The harvested rainwater can supplement mains water supply on the farm, but cannot replace it.
7. The installation of commercially-made filters improves the level of water quality achieved.
8. Correct installation and sealing of all joints in the collection system prevents contamination from farmyard run-off and ensures a higher quality of water collected.
9. Current charges for mains water supply are an inhibiting factor to the installation of rainwater harvesting systems by farmers.
10. The cost and size of storage facilities for harvested rainwater in an agricultural situation can be substantial.
11. A simple and effective maintenance programme is required.
12. All design and installation of rainwater harvesting systems should be carried out by competent/specialist trained personnel.

6.2 RECOMMENDATIONS

1. Rainwater harvesting systems should be considered as a viable option when supplementing treated mains water for non-potable use.
2. Further use of harvested rainwater in agricultural applications should be explored through TEAGASC.
3. Monitor closely further developments in rainwater harvesting technology.
4. A targeted approach should be undertaken on the use of rainwater harvesting especially for those involved in building design and construction.
5. Consideration should be given to an awareness/education programme on the benefits that accrue from rainwater harvesting.
6. Basic advice/tips should be provided for those considering the installation of a rainwater harvesting system.

APPENDICES

APPENDIX 1
RWH WATER QUALITY, LITERATURE REVIEW & PUBLIC HEALTH ISSUES

RAINWATER HARVESTING WATER QUALITY

The Path of Contamination

When considering the water quality of a rainwater harvesting system, it is useful to observe the complex path a contaminant must follow in order to enter a human being. The usual paths are shown in Figure 1.

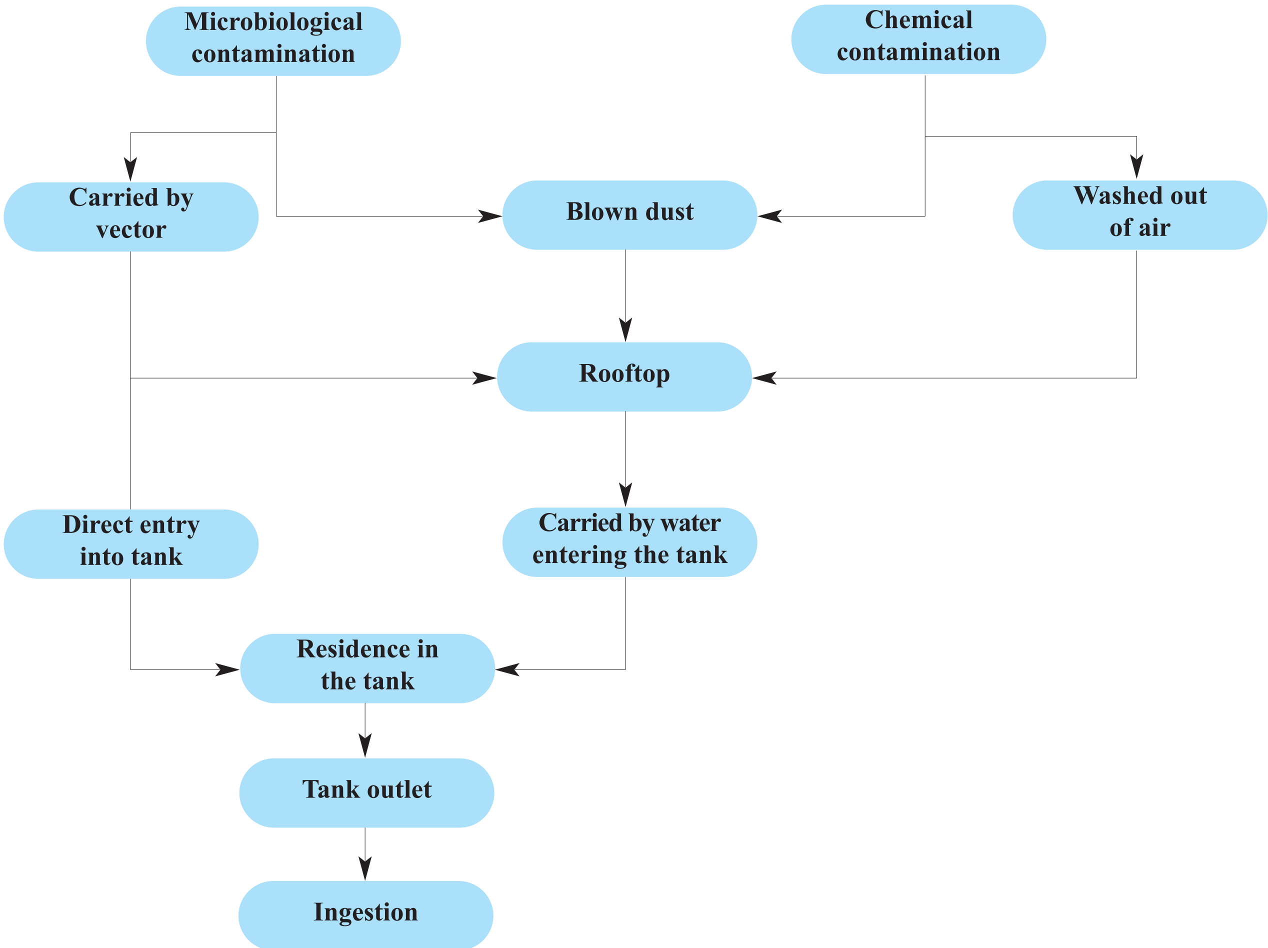


Fig 1 Contamination pathways for Rainwater Harvesting (Thomas, 2007).

Rainwater Harvesting Treatment Processes

Fig 1 illustrates the possible contaminant pathway routes within a typical rainwater harvesting system. As the water passes through the various stages in the system it is exposed to processes that simultaneously reduce/eliminate the microbiological load. Fig 2 illustrates these treatment processes. A domestic rainwater catchment contains a number of components. The roof top provides the entry point for the majority of contaminants, although parallel processes simultaneously reduce the microbiological load through UV, heat, and desiccation. Within the tank, it has been shown that biofilms actively remove heavy metals and organics from the water column, while sedimentation and surface flocculation also remove contaminants from the available water supply. Tank water must pass through a pump and possibly through a hot water system before human contact, which impose sudden stresses on bacteria, disrupting cell structure and integrity.

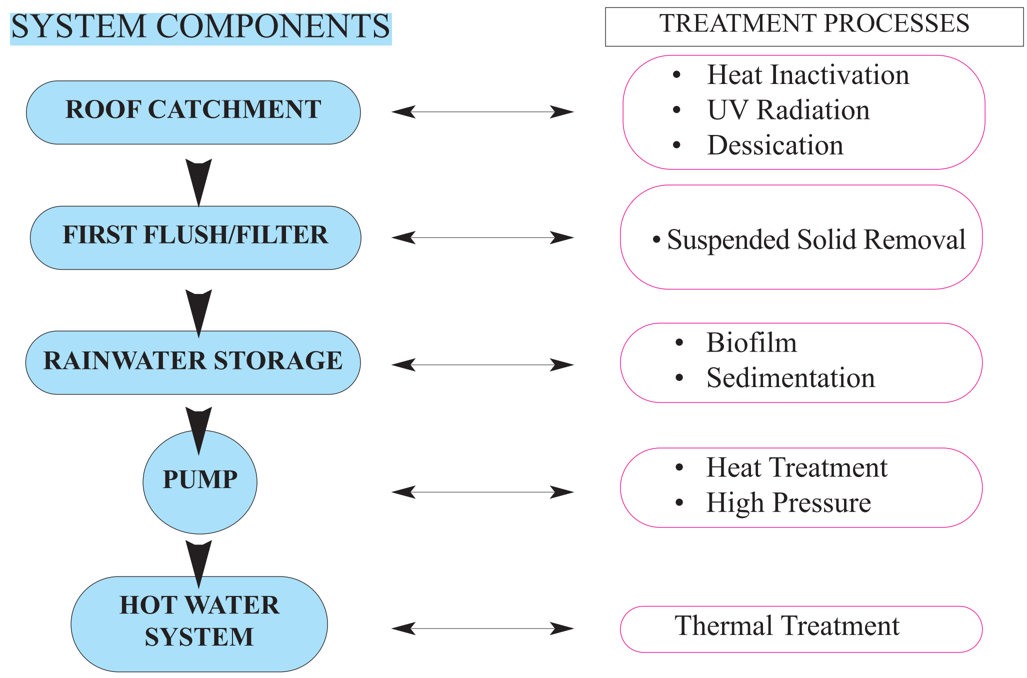


Fig 2 Treatment processes within a rainwater harvesting system.

Each of these components influences water quality within the collection train. Spinks et al. [2003] identified significant improvements in water quality throughout the catchment train of Figtree Place, a water sensitive urban design retrofit project in Newcastle, Australia. Results of the water quality are reproduced in Table 1.

Parameter	Roof	Tank Surface	Tank Tap	HWS
Faecal Coliforms (CFUs/100ml)	231	119	20	0
Total Coliforms (CFUs/100ml)	776	834	166	0
HPC (CFUs/ml)	1,961	3,256	331	3
Pseudomonas (CFUs/100ml)	146,723	6,768	7,544	0
Ammonia (mg/l)	0.22	0.1	0.27	0.18
Nitrate (mg/l)	0.87	0.06	<0.05	<0.05
Lead (mg/l)	0.02	<0.01	<0.01	<0.01

Table 1 Water Quality at various locations in an urban rainwater harvesting system (Spinks 2003).

Fig. 3 illustrates the results from a study of rainwater harvesting systems in Sri Lanka. Concentrations of coliforms per 100ml of rainwater varied according to seasonal factors, the greatest deterioration occuring during rainfall that followed a dry spell. As the volume and intensity of rain increased, however, the level of coliforms decreased once more. This demonstrates that wash-out impacts considerably on the harvested rainwater quality.

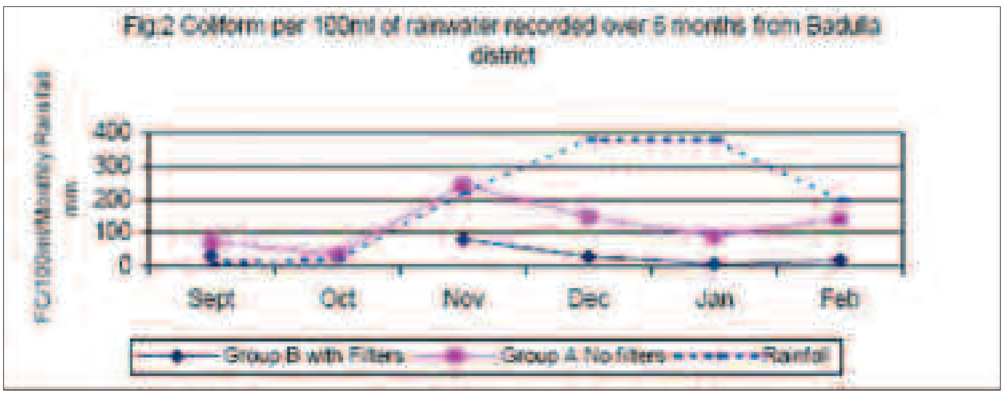


Fig 3 Rainwater Harvesting Water Quality, Sri Lanka (Ariyananda T. N. 1999).

Further evidence of the seasonal effects of harvested rainwater quality can be deduced from a study by IRC (Thomas, 2007), the results of which are presented in Fig. 4. Levels of indicator bacteria rise after rain and then fall over time until the next rain. Reductions of 90% of Total Coliforms have been noted after about 3 days, though this varies somewhat with local conditions.

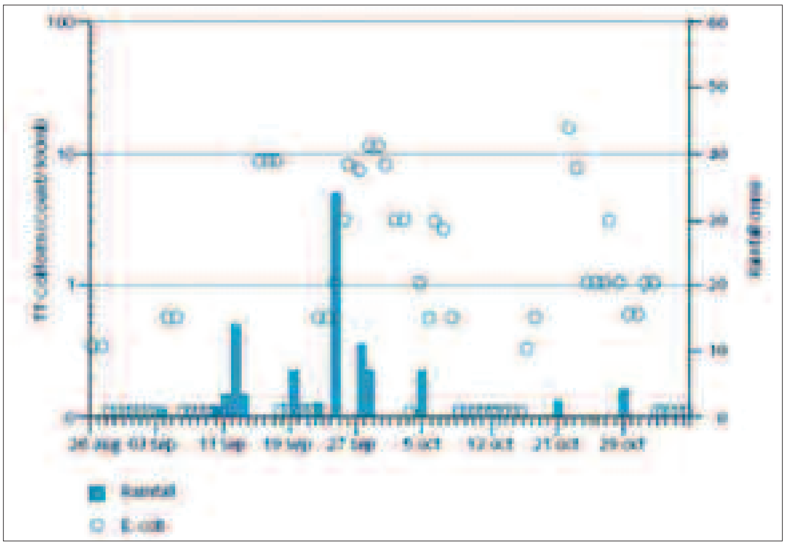


Fig 4 Episodes of rainfall and average of indicator bacteria taken from tanks in one location.

Further harvested rainwater quality studies conducted in countries with different systems, climate and locations, record zero *E. coli* in 35-55% of the samples collected, thus complying with WHO recommended standards. Many other samples recorded less than 100 *E. coli*/100 ml of rainwater, falling into the "intermediate risk" according to the WHO standard. This is far below the *E. coli* levels recorded from other rural sources, such as wells. Studies from a project in Addis Ababa, Ethiopia have shown that *E. coli* levels in rainwater tanks are influenced by rainfall (Figure 5). High levels are recorded immediately after rain. However, bacterial levels decrease within 4-7 days, if no fresh contamination occurs (Figure 6).

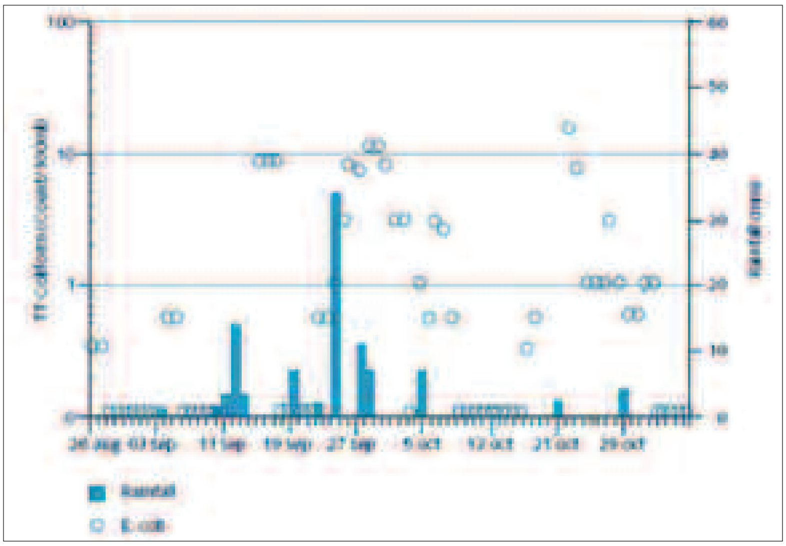


Fig 5 *E. coli* recorded in samples taken from a rainwater tank in Addis Ababa (T. Ariyananda, 2003).

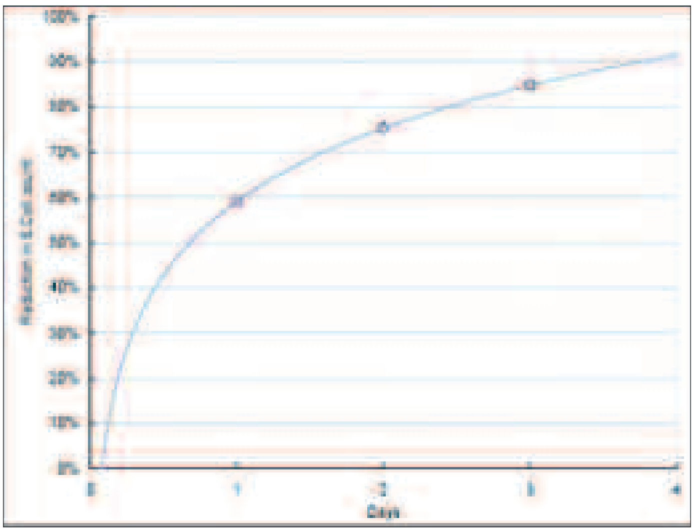


Fig 6 Bacterial die-off recorded from rainwater tanks (T. Ariyananda, 2003).

Chemical and Physical Quality of Harvested Rainwater

The chemical and physical quality of rainwater may not directly cause a health risk but it can influence water disinfection methods and promote bacterial growth. However, the physical and chemical quality of drinking water directly affects its acceptability to consumers. High levels of turbidity can protect micro-organisms from the effect of disinfection, stimulate the growth of bacteria and give rise to significant chlorine demand. Disinfection requires that turbidity is less than 5 NTU; ideally, median turbidity should be below 1 NTU. Turbidity recorded from most rural locations are below 5 NTU. In urban locations turbidity can be high due to local pollution and dust settling on the roofs. Turbidity in tanks correlates with rainfall pattern, high turbidity being recorded soon after rain (Figure 7).

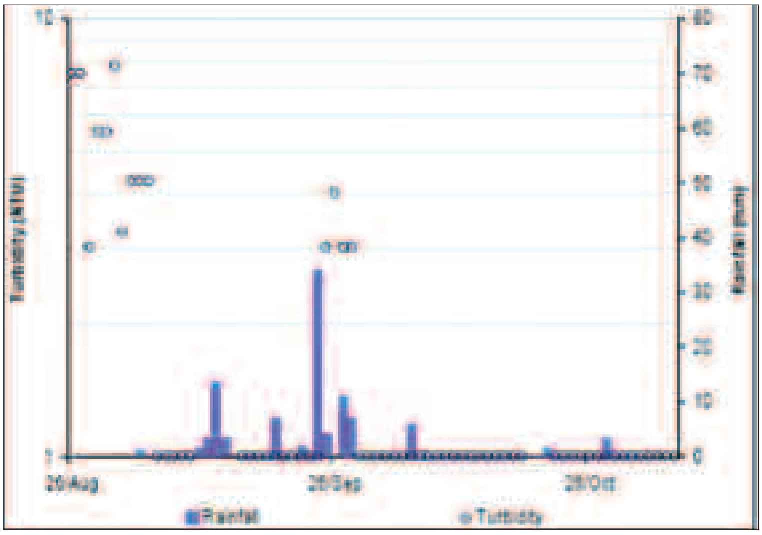


Fig 7 Turbidity levels in rainwater tanks in relation to rainfall amounts.

Harvested Rainwater Quality Study, Australia, 1998

Figtree Place is a water sensitive urban redevelopment consisting of 27 residential units located in Hamilton, an inner suburb of Newcastle, NSW, Australia. The site uses rainwater stored in tanks to supply hot water and toilet flushing demand. A two-year monitoring program for roof water, tanks and hot water systems revealed that water quality improves in the roof to tank to hot water system treatment chain. Although the quality of rainwater collected from roofs occasionally exceeded the guideline values for Ammonia, pH and Lead, samples of rainwater from tanks and hot water systems were found compliant with the chemical and metals parameters (except pH) in the Australian Drinking Water Guidelines. The water treatment processes of settlement, sorption and bio-reaction appear to operate in tanks to improve water quality. Table 2 presents the results of the sampled rainwater quality from the underground rainwater storage tanks.

Parameter	Unit	Average	Maximum	Minimum	Guideline
Faecal Coliforms	(CFU/100ml)	0	0	0	0
Total Coliforms	(CFU/100ml)	0	0	0	0
Heterotropic Plate Count	(CFUs/ml)	10	30	0	NA
Pseudomonas SPP	(CFU/100ml)	110	330	0	NA
Temperature	°C	19	21	16	NA
Sodium	mg/l	4.03	4.90	3.17	180
Calcium	mg/l	1.19	1.68	0.70	200
pH		6.00	6.10	5.90	6.5-8.5
Dissolved solids	mg/l	105.00	112.00	98.00	500
Suspended solids	mg/l	97.55	178.00	17.10	500
Chloride	mg/l	6.65	7.60	5.70	250
Nitrate	mg/l	0.05	0.05	0.05	3
Nitrite	mg/l	1.30	1.50	1.10	50
Sulphate	mg/l	2.16	3.90	0.42	250
Ammonia	mg/l	0.20	0.20	0.20	0.5
Lead	mg/l	<0.01	<0.01	<0.01	0.01
Iron	mg/l	0.06	0.10	<0.01	0.3
Cadium	mg/l	<0.002	<0.002	<0.002	0.002

Table 2 Water Quality from rainwater tanks at Maryville (Coombes 2003).

Rainwater stored in the storm water retention tanks was used to supply electric hot water storage systems. The average, maximum and minimum parameter values for water quality in the hot water systems are shown in Table 3.

Parameter	Unit	Average	Maximum	Minimum	Guideline
Faecal Coliforms	(CFU/100ml)	0	0	0	0
Total Coliforms	(CFU/100ml)	0	0	0	0
Heterotropic Plate Count	(CFUs/ml)	3	6	0	NA
Pseudomonas SPP	(CFU/100ml)	0	0	0	NA
Temperature	^{o}C	57	65	52	NA
Sodium	mg/l	4.44	9.80	1.50	180
Calcium	mg/l	10.03	22.90	2.80	200
pH		6.24	7.50	4.70	6.5-8.5
Dissolved solids	mg/l	94.43	255.00	2.00	500
Suspended solids	mg/l	0.78	2.00	0.20	500
Chloride	mg/l	10.02	35.10	3.50	250
Nitrate	mg/l	<0.05	<0.05	<0.05	3
Nitrite	mg/l	0.80	3.00	0.05	50
Sulphate	mg/l	9.56	36.40	2.70	250
Ammonia	mg/l	0.18	1.00	<0.01	0.5
Lead	mg/l	<0.01	<0.01	<0.01	0.01
Iron	mg/l	0.02	0.10	<0.01	0.3
Cadium	mg/l	<0.002	<0.002	<0.002	0.002

Table 3 Water quality from hot water systems at Figtree Place (Coombes 2003).

Although water supplied from the storm water retention tanks to hot water systems exceeded the Australian guideline values for Faecal Coliforms and Total Coliforms, it was found that all coliform bacteria were removed by the hot water systems in 23 separate samples. The pH value still remained low, but all the other average parameter values for hot water quality (Table 2.4) complied with the guidelines. The average parameter value for pH (6.24) is marginally lower than the range (6.5 – 8.5) required under the guidelines. The pH value improved from 5.95 in the roof water to 6.24 in the hot water. The average, maximum and minimum temperatures of the hot water samples were 57^{o}C, 65^{o}C and 52^{o}C respectively. The processes of pasteurization and tyndallisation (small perturbations of water temperature) had apparently acted to eliminate Faecal Coliforms, Total Coliforms and Pseudomonas Spp. in the hot water systems.

PUBLIC HEALTH RISKS ASSOCIATED WITH RWH

For pathogen-contaminated water to cause illness in humans, the pathogens must have an available route of infection and must overcome the defence barriers of the human body. Routes of infection may include inhalation or ingestion, with host barriers including, stomach acidity, competition by natural gut flora, and immunological responses, including acquired immunity. Successful infection by the pathogen is ultimately dependent on the presence of the pathogen in the water in concentrations above the minimum infective dose. Biocidal environments, such as hot water systems maintained at adequate temperatures, inhibit the development of concentrations sufficient to cause infections.

The final, and perhaps greatest, sets of barriers for pathogenic bacteria are those of the natural defence mechanisms of the human body. The highly acidic conditions in the stomach and the indigenous gut flora efficiently prevent many potentially harmful micro-organisms from infecting the host. For successful infection of a human by a few bacteria, the initial concentration must be above the minimum infective dose. This minimum infective dose is not a set concentration under which no infection is ever possible, but presents a minimum dose that, under typical conditions, is highly improbable of causing illness. The minimum infective dose is dependent on a number of factors including the virulence of the bacterial species, as well as the condition of the host, such as immunological and nutritional status, and previous exposure to the pathogen.

The World Health Organisation has recently changed its direction with water quality guidelines from recommending that no detection be made of certain pathogenic bacterial species to allowing low levels of these bacteria. This was a result of the acknowledgement that ingested bacteria rarely successfully infect the human body and that acquired immunity is an important health defence mechanism against water pathogens.

Reported Illnesses Associated with Rainwater Harvesting

There are only a handful of reported cases of illness associated with the use of RWH systems. This is because well-maintained RWH systems tend to give fairly clean water and because outbreaks are typically confined to one system (household) and do not become widespread as with centralised water supply. Outbreaks tend not to be reported unless they involve a large number of people or take place on commercial premises. Those cases that are reported tend to cite poor RWH practice, accidental contamination or immuno-compromised subjects, or are cases where rainwater consumption is only one of a number of possible causes of the outbreak. About 3 million Australians currently use rainwater from tanks for drinking [ABS, 1994] in urban and rural regions, with no reported epidemics or widespread adverse health effects. Fuller et al. [1981], Mobbs et al. [1998] and Cunliffe [1998] found that the quality of rainwater was often adequate for potable uses provided that the rainwater tank and roof catchment were subject to adequate maintenance.

Some studies suggest that drinking rainwater collected from roof surfaces is a potential source of human illness. Simmons et al. [2001] found that the rainwater supplies in Auckland NZ sometimes exceeded drinking water guidelines for lead and microbial indicator organisms. Importantly, the presence of potential pathogens Salmonella Spp. and Cryptosporidium were detected in one and two samples respectively. No illness was reported. The presence of Aeromonas Spp. was found in 20% of samples. Residents reporting gastrointestinal symptoms in households were more likely to have Aeromonas Spp. in their rainwater supply than those who did not experience gastrointestinal symptoms. It was also found that houses with roofs that partially consist of lead or galvanised iron were more likely to have lead contamination in their rainwater supply [Simmons et al., 2001].

Brodribb et al. [1995] reported that an elderly immuno-compromised woman was subject to recurring Campylobacter Fetus infections. Campylobacter Fetus was found in the rainwater tank the woman used for her drinking water supply. Koenraad et al. [1997] and Whelan et al. [1983] explain that many birds carry and excrete Campylobacter. Cunliffe [1998] suggest that maintenance of roof and gutter system will reduce the likelihood of the presence of Campylobacter in rainwater supplies. Reptiles [Freidman et al., 1998 and Minette, 1984] and frogs [Bartlett et al., 1977] are reported to be a source of Salmonella. Cunliffe [1998] states that the probable source of indicator bacteria detected in rainwater tanks is excreta from small animals, reptiles and birds. The transfer of pathogens via these sources is considered to be less hazardous than that of human faeces because human faeces are more likely to contain pathogens [Cunliffe, 1998]. Contamination of rainwater stored in tanks can be minimised by sealing all inlet and outlet points with mesh to eliminate access by vermin to the tank, keeping roof gutters clear of debris and installation of a first flush device to separate the first part of roof runoff [Cunliffe, 1998; Gee, 1993 and Duncan and Wight, 1991].

Gee [1993] reported exceedance of drinking water guidelines for microbial indicator organisms and pH in water from 12 poorly maintained rainwater tanks in the Sydney region although rainwater was sampled from the water surface rather than the point of supply. Water from all of the rainwater tanks complied with the chemical parameters of the Australian Drinking Water Guidelines (except pH). Samples taken from the sludge zone in two rainwater tanks revealed lead levels of 0.6 mg/l and 0.29 mg/l although the corresponding lead concentrations were <0.01 mg/L and 0.02 mg/L at the water surface [Gee, 1993]. A similar result was found at the Figtree Place experiment (Coombes, 2003). It is believed that the majority of chemical contamination does not remain in stored rainwater: rather it settles to the bottom of rainwater tanks.

Coombes et al., [2003] report in a literature review of studies from the use of rainwater harvesting in Australia that the majority of studies that found that rainwater stored in tanks was of poor quality made this claim on the basis of the presence of Coliform bacteria in the water. The presence of Coliform bacteria is assumed to indicate recent faecal contamination of water that may indicate the presence of pathogens. However, Coliform bacteria occur naturally in the environment and are most likely to be found in untreated waters. The isolation of Coliform bacteria in rainwater is unlikely to indicate recent faecal contamination and even less likely to indicate the presence of pathogens. Moreover the majority of water-borne pathogens originate from human faecal material (Section 4.2). Citizens do not defecate on roofs, nor even in household yards. It is highly improbable that the majority of pathogens can be transported from roofs to adequately sealed above ground tanks. It is also unlikely that pathogens from roofs and household yards can be transported to adequately sealed underground tanks. Pathogens are rarely found in rainwater tanks (Section 4.2). Claims that rainwater is unsafe due to the presence of Coliform bacteria are questionable. Given that rainwater is unlikely to be contaminated by sewage, more intensive testing is required to determine the presence of pathogens in rainwater.

Epidemological Studies

In Australia, epidemiological studies provide few conclusive links between the presence of pathogens in water and human illness. Many bacteria of concern have not been linked to disease outbreaks, despite being identified in drinking water supplies. Australia's Drinking Water Guidelines identify several examples, including Klebsiella spp. and Aeromonas spp. These have been detected in drinking water, but there is no evidence that they have caused disease. Enteropathogenic *E. coli* is rarely able to become established in a healthy human and even more rarely causes infection [NHMRC, 1996].

Similarly, within rainwater tanks little epidemiological data exists to establish the relationship between the presence of pathogens and illness. While the acceptability, in terms of health risk, of using rainwater for hot water purposes remains unresolved, it would appear from these authors that no links have been made between the use of hot water systems supplied by rainwater and gastrointestinal or respiratory illness. Infection from hot water systems may come from either the ingestion or inhalation of pathogens. Arguably the most significant health risk in hot water systems comes from the respiratory pathogen L. pneumophila. Due to the route of infection by Legionella in the human body, L. pneumophila bacteria must be entrapped in aerosols and inhaled in order for the successful infection of the respiratory tract. The ingestion of L. pneumophila is harmless as they are unable to cope with the stresses of the gastrointestinal tract. There may by a potential health risk from showering in hot water if the water supply contains L. pneumophila and the hot water is maintained below 60°C, as contaminated aerosols may be produced. However, this risk is equally applicable to mains water users. The results of a recent survey showed that hot water systems are rarely used for drinking purposes [Coombes et al., 2003]. Furthermore, the recent results of Spinks et al. [2003] showed that enteric pathogen populations were reduced quickly in hot water systems.

The defence mechanisms of the body and the increasing immunological resistance to pathogens through acquired immunity from exposure to low levels of pathogens may actually mean that it is microbiologically safer to use rainwater for all purposes, including drinking. Research into gastrointestinal illnesses in people drinking tank water as opposed to people drinking treated mains water suggests that this is the case [Heyworth, 2006]. Heyworth concluded, after an epidemiological investigation using 1,000 participants, that those drinking chlorinated filtered mains water reported higher rates of gastrointestinal sickness than those drinking rain harvested tank water.

APPENDIX 2
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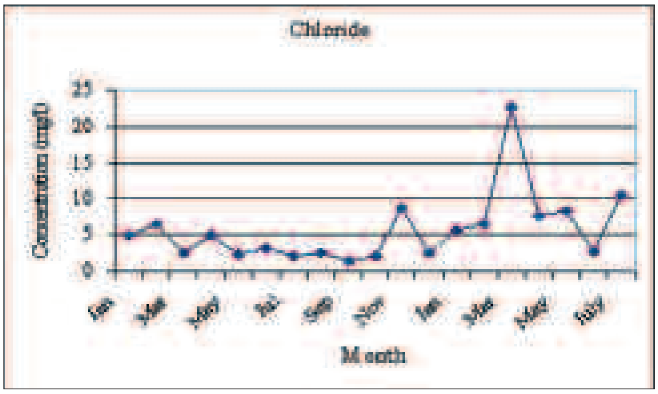
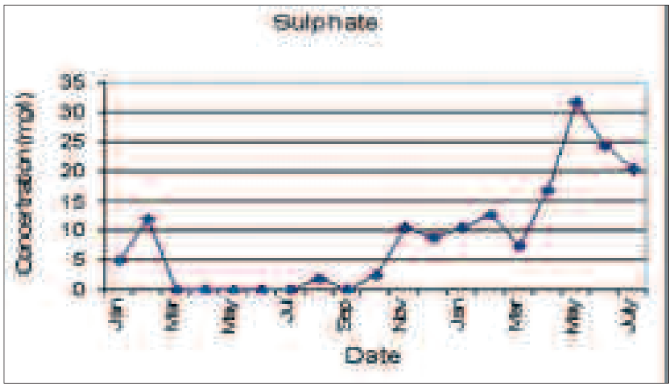
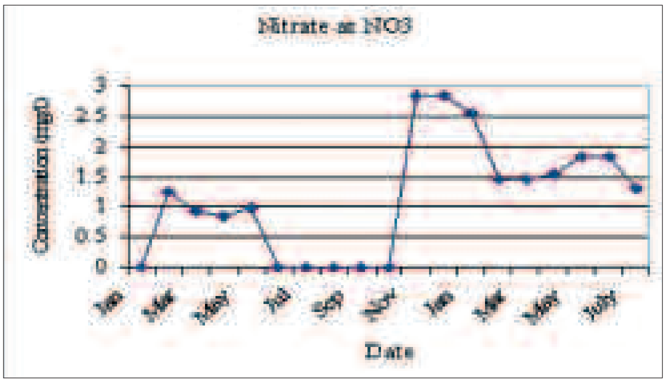
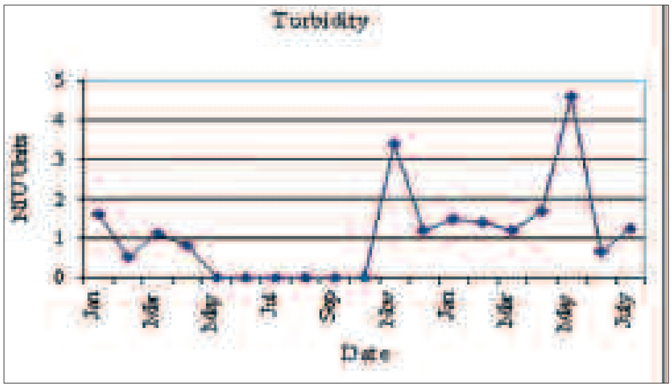
APPENDIX 3

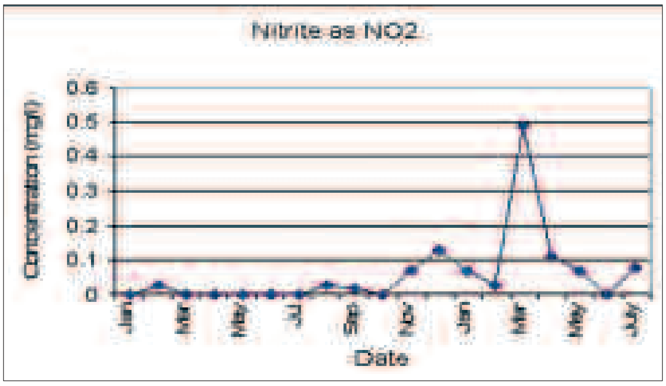
MONTHLY RAW WATER QUALITY RESULTS FROM THE DOMESTIC SITE (BALLINABRANNAGH)

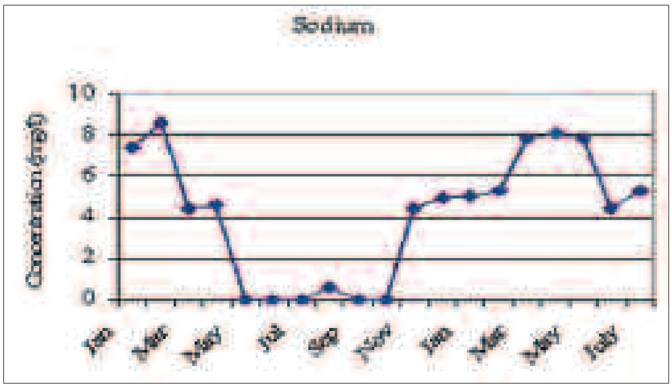


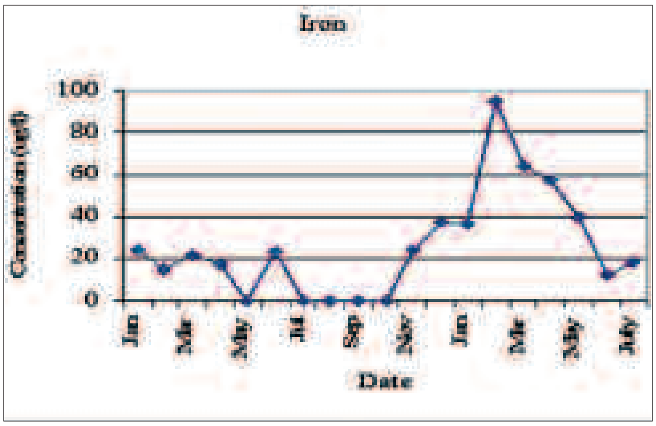


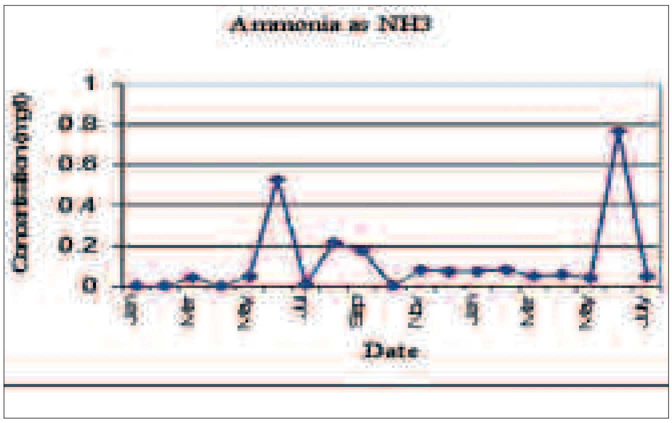


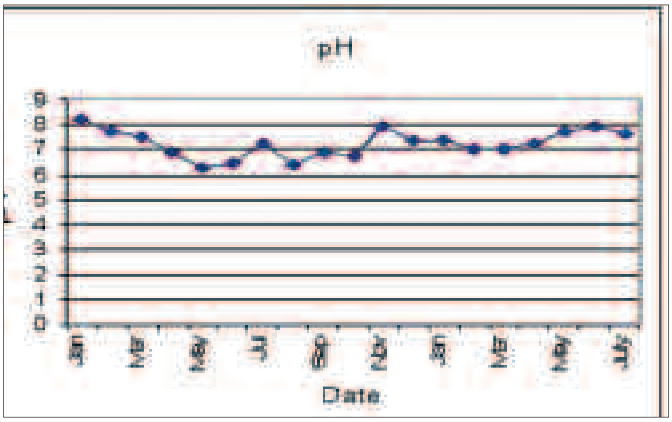


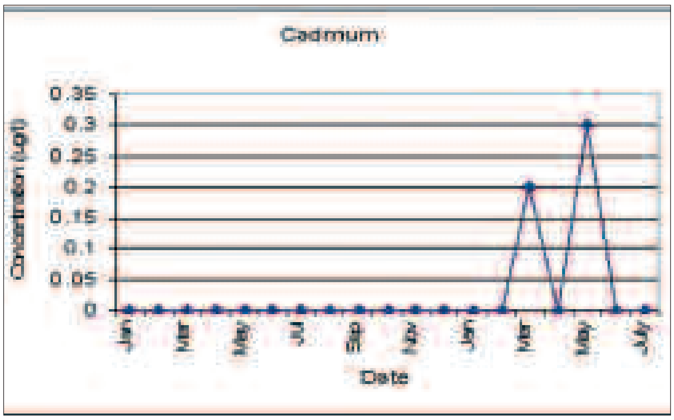


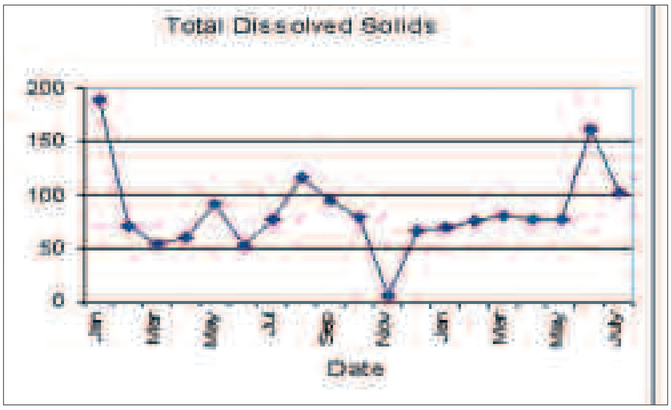


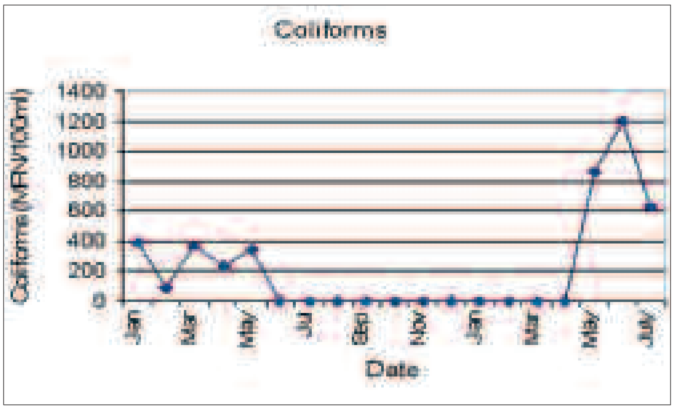


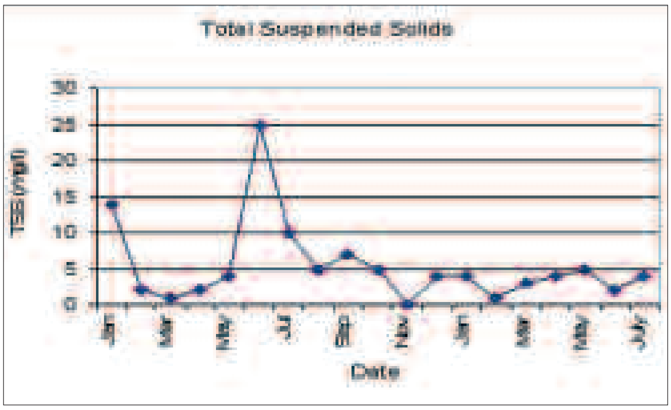


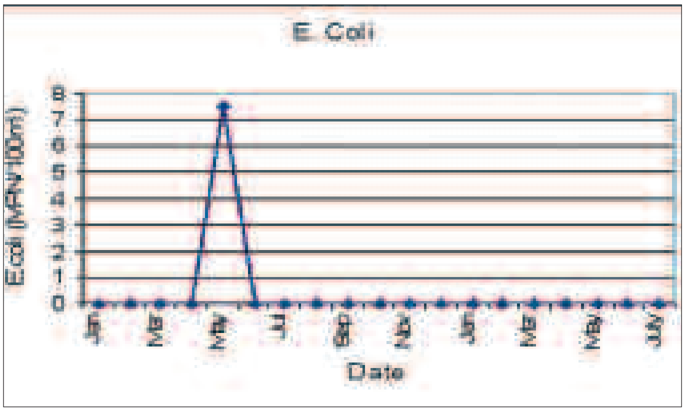

pH
9
8
7
6
5
4
3
2
1
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date

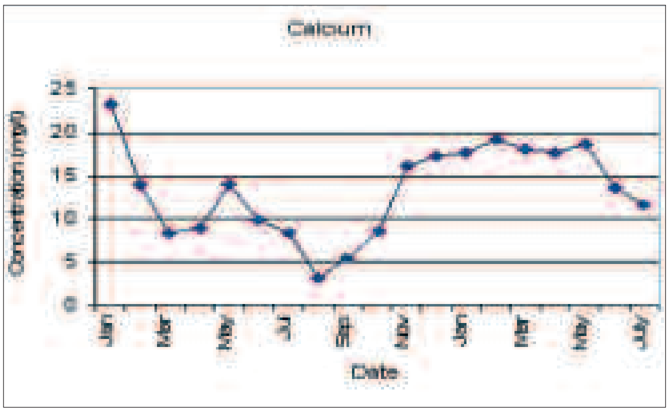

Cadmium
Concentration (ug/l)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date

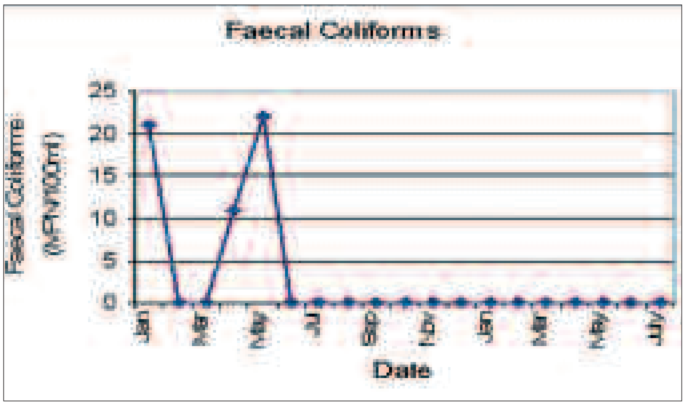

Total Dissolved Solids
200
150
100
50
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date

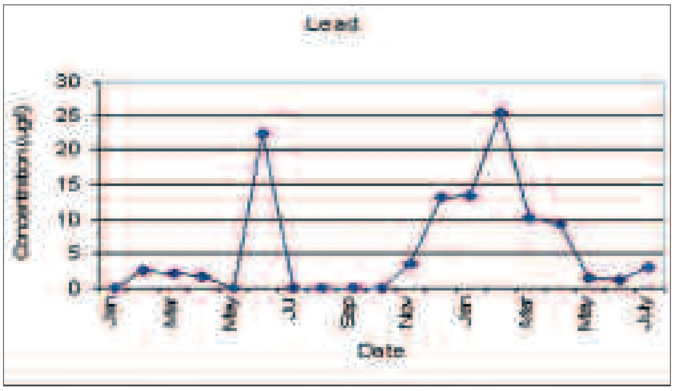

Coliforms
Coliforms (MPN/100ml)
1400
1200
1000
800
600
400
200
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date


Total Suspended Solids
TSS (mg/l)
30
25
20
15
10
5
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date


E. Coli
E.coli (MPN/100ml)
8
7
6
5
4
3
2
1
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date


Calcium
Concentration (mg/l)
25
20
15
10
5
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date


Faecal Coliforms
Faecal Coliforms (MPN/100ml)
25
20
15
10
5
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date


Lead
Concentration (ug/l)
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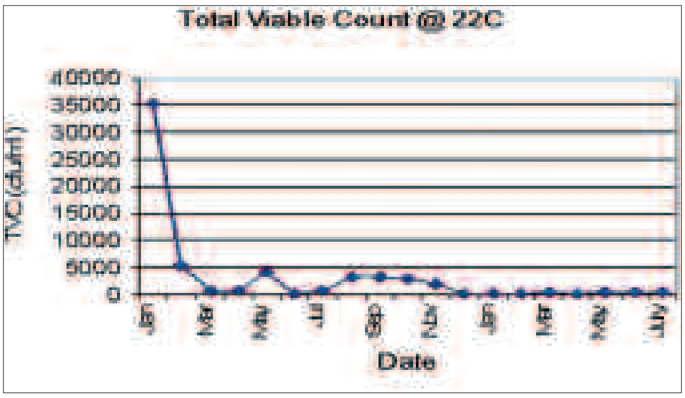
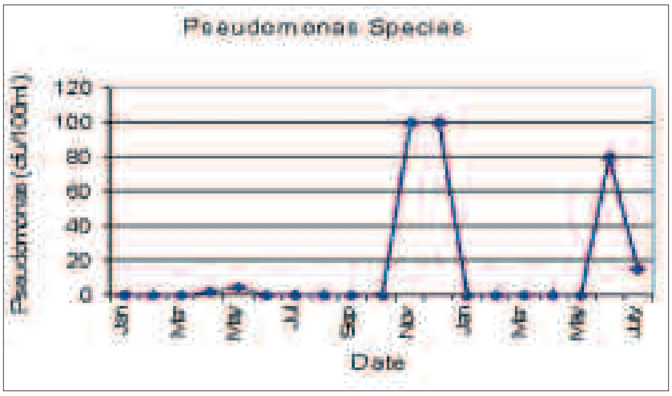
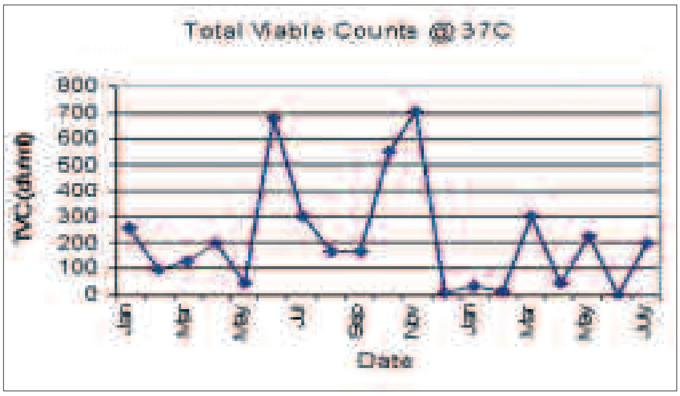
25
20
15
10
5
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date


Total Viable Count @ 22C
TVC (cfu/ml)
40000
35000
30000
25000
20000
15000
10000
5000
0
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
July
Date



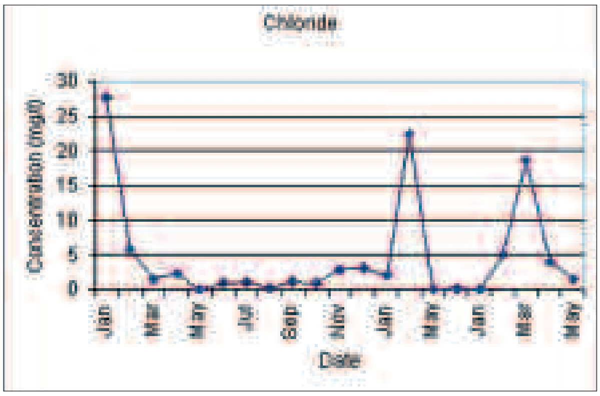
Pseudomonas Species
Pseudomonas (cfu/100ml)
120
100
80
60
40
20
0
Date

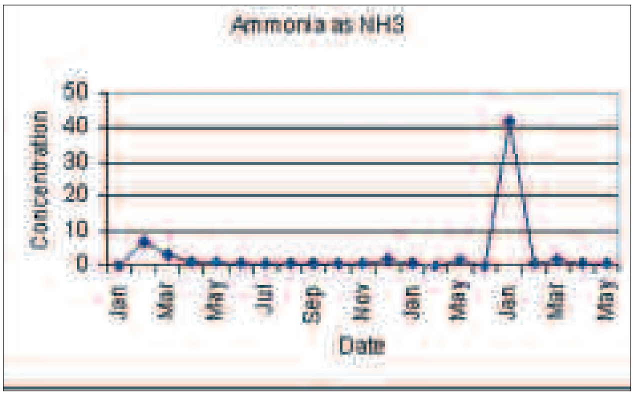


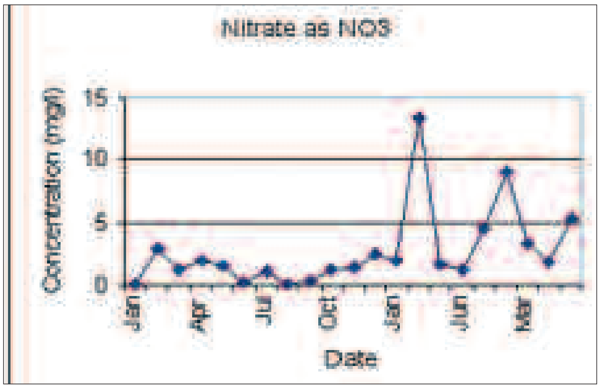
Total Viable Counts @37C
TVC(cfu/ml)
800
700
600
500
400
300
200
100
0
Date

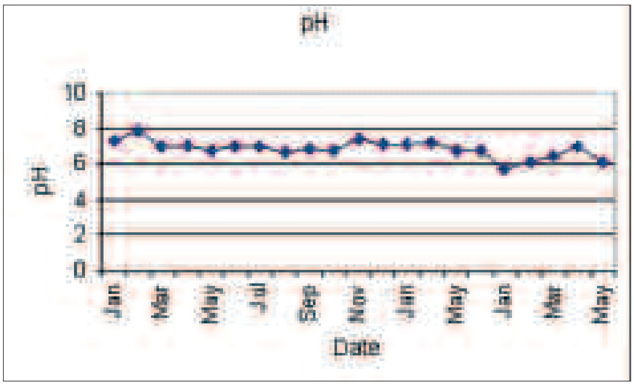
APPENDIX 4

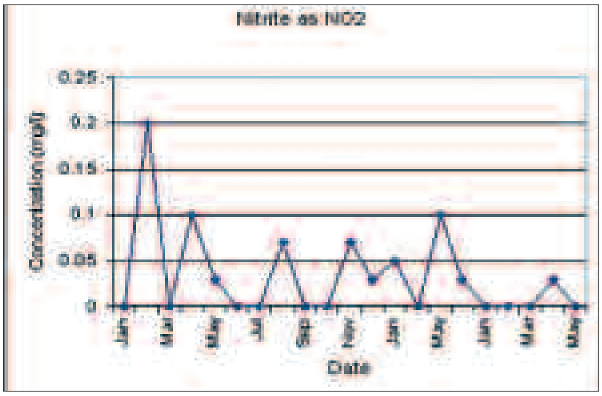
MONTHLY RAW WATER QUALITY RESULTS FROM THE AGRICULTURAL SITE (CLONALVY)

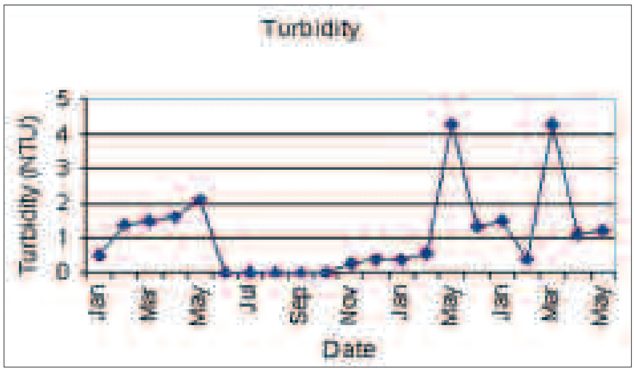


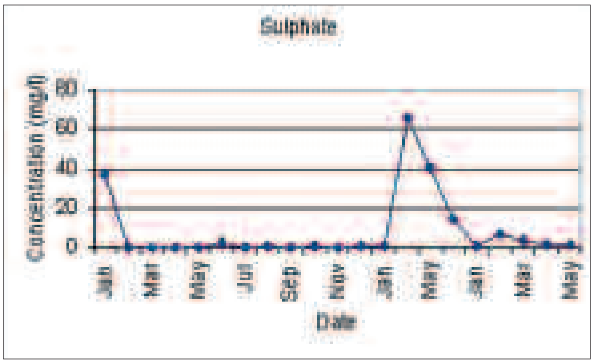


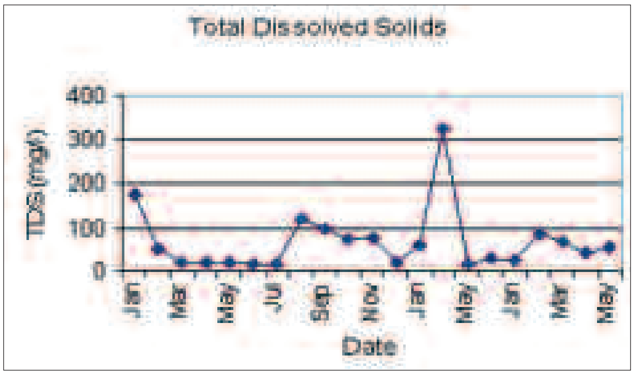


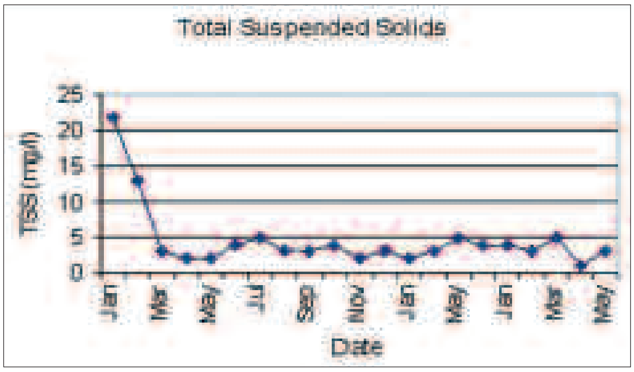


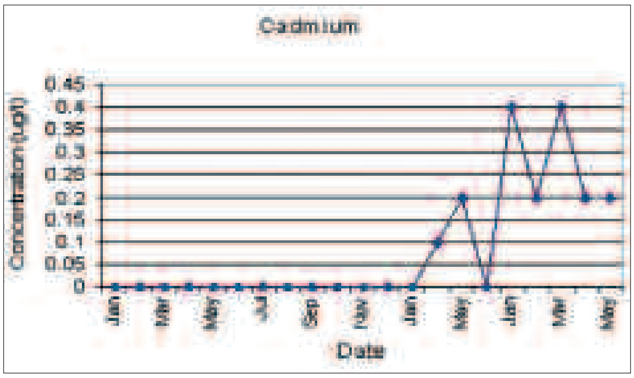


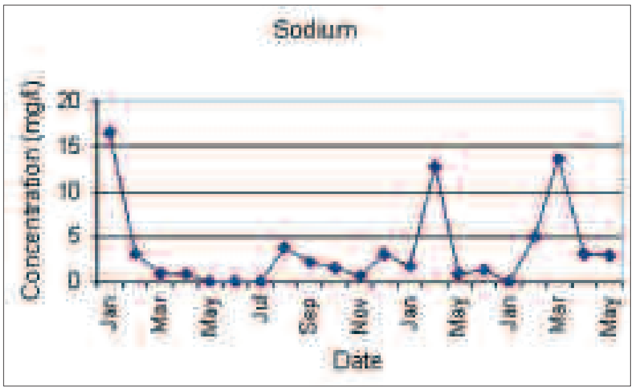


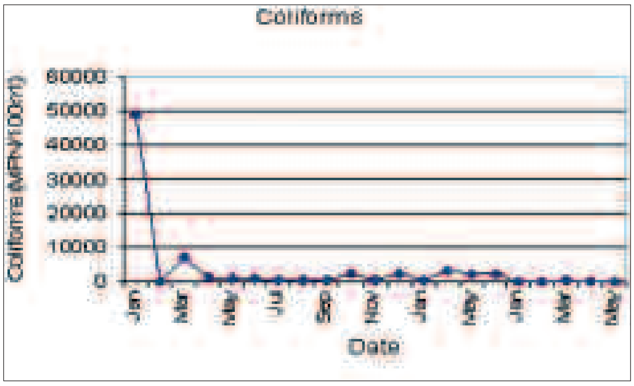


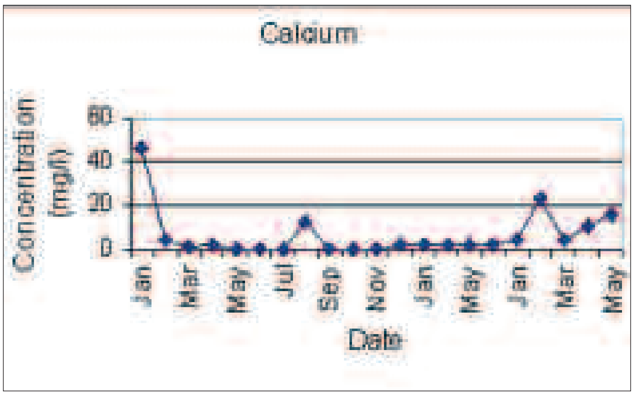


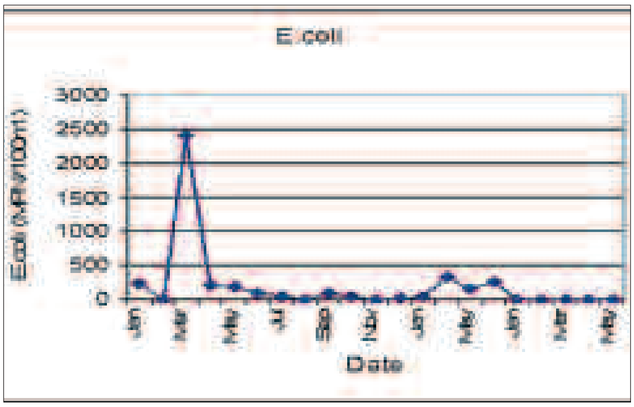

Total Suspended Solids
TSS (mg/l)
Date

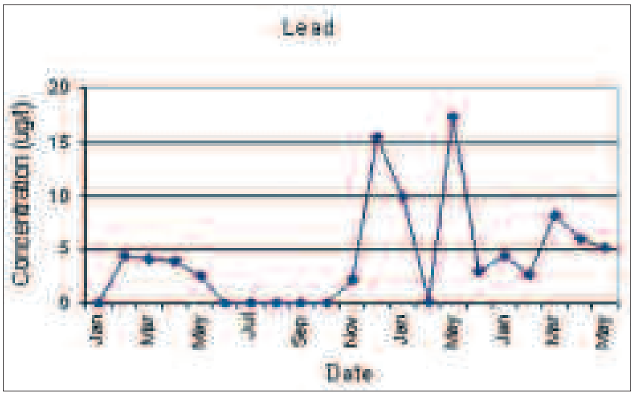

Cadmium
Concentration (ug/l)
Date

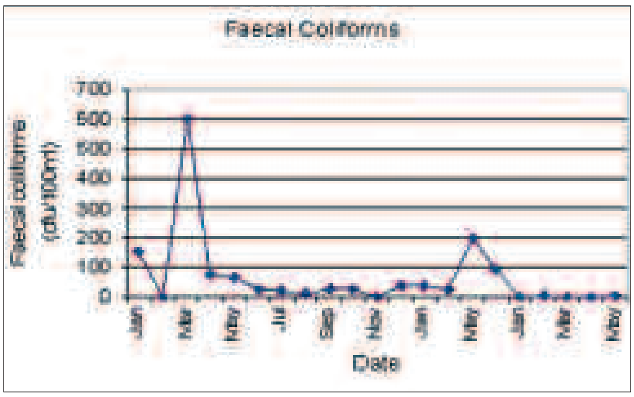

Sodium
Concentration (mg/l)
Date

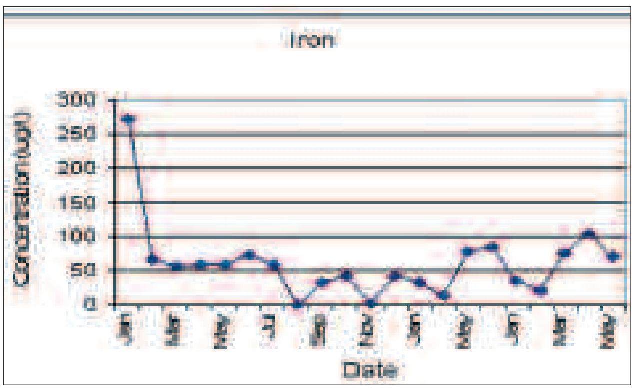

Coliforms
Coliforms MPN/100ml)
Date

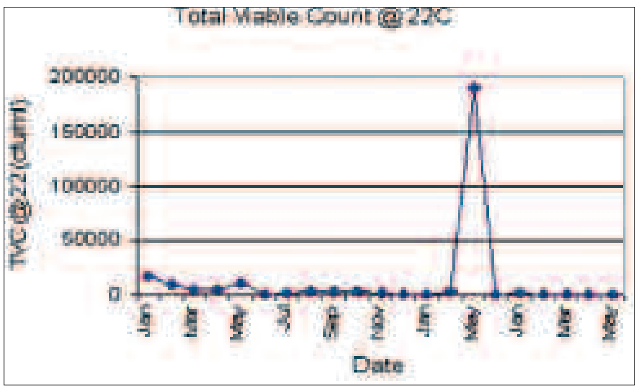

Calcium
Concentration (mg/l)
Date

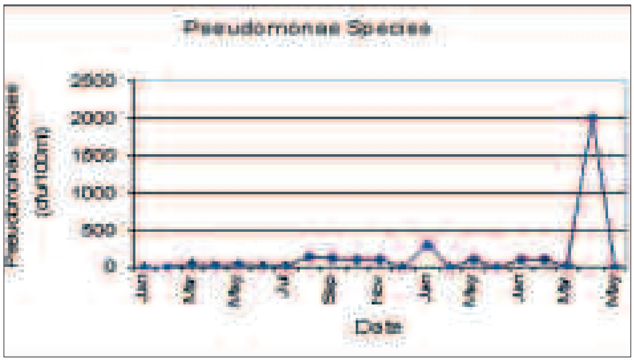

E.coli
Ecoli (MPN/100ml)
Date

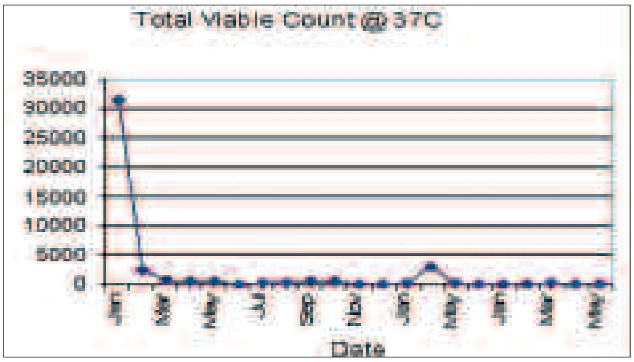

Lead
Concentration (ug/l)
Date


Faecal Coliforms
Faecal coliforms (cfu/100ml)
Date


Iron
Concentration (ug/l)
Date


Total Viable Count @ 22C
TVC @ 22 (cfu/ml)
Date


Pseudomonas Species
2500
2000
1500
1000
500
0
Date


Total Viable Count @ 37C
35000
30000
25000
20000
15000
10000
5000
0
Date