National Development Plan 2007 - 2013

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

STRIVE
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On-site Wastewater Treatment: Investigation of Rapid Percolating Subsoils, Reed Beds and Effluent Distribution

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

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EPA Strive Programme 2007–2013

On-site Wastewater Treatment: Investigation of Rapid Percolating Subsoils, Reed Beds and Effluent Distribution

(2005-MS-15)

STRIVE Report

End of Project Report available for download at http://erc.epa.ie/safer/reports

Prepared for the Environment Protection Agency

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

The safe disposal of on-site wastewater is essential for the protection of both groundwater and surface water resources in Ireland. This project reports the results from field trials carried out on three separate sites investigating the attenuation of chemical and microbiological pollutants in domestic wastewater through relatively fast percolating subsoil and also through reed bed treatment systems. In addition, the distribution performance of several different devices designed to split the on-site effluent evenly across the percolation areas was evaluated.

Two sites with single houses were chosen with relatively fast percolating subsoil conditions, Site A in Co. Kildare with T-value[1] of 3.7 and Site B in Co. Wicklow with T-value of 4.5. The on-site wastewater effluent was treated by a septic tank on Site A and secondary treatment RBC package plant on Site B and then the respective effluents split into two whereby half discharged into a standard percolation area on each site and the other half discharged to horizontal subsurface treatment reed beds. Samples of the respective effluents percolating through the subsoil were collected at different depths beneath the percolation areas for more than two-year trial periods, as well as monitoring the treatment performance of the reed beds alongside. A third site, Site C in Wexford, was also monitored to investigate the performance of packaged reed bed modules receiving secondary treated effluent.

The results showed that higher permeability subsoil acted to reduce the biomat lengths and thus increase the areal effluent loading rate on the percolation areas. The effluent in the trenches receiving septic tank effluent was spread over a biomat length of roughly 10 m, compared to the biomats in the percolation trenches receiving package-plant, secondary-treated effluent which were considerably shorter and did not extend beyond 0.5 m. In general, however, the septic tank and percolation system provided a comparable treatment performance with respect to groundwater protection to the packaged secondary treatment system with the exception of nitrogen and viral indicators, which underwent enhanced attenuation in the subsoil receiving septic tank effluent. The use of three different bacteriophage tracers (MS2, φX174, PR772) on the sites indicated that enteric viruses in on-site wastewater effluent are likely to be totally removed after a depth of 0.95 m of unsaturated subsoil underneath trenches receiving septic tank effluent. Some phage concentrations were still detected at this depth beneath percolation trenches receiving secondary treated effluent, due to the much higher hydraulic loading – a result of muted biomat development. Although 0.95 m of unsaturated subsoil beneath the percolation pipes significantly reduced the enteric bacteria in both types of on-site effluent, there were isolated incidences of low concentrations of *E. coli* found in the subsoil on both sites at this depth.

The horizontal flow subsurface reed bed receiving septic tank effluent was effective at reducing organic, suspended solids and bacteriological loads but not nutrients or the indicator viruses. The reed bed also acted to slightly enhance the hydraulic loading over the course of a year in an Irish climate. Equally, the tertiary treatment reed beds on Sites B and C achieved further polishing of the secondary effluent in terms of organics and enteric bacteria and some removal of nutrient loads. The microbiological quality of the final effluent however, still contained significant numbers of human enteric bacteria and high levels of phosphorus and the beds did not act to attenuate the bacteriophage indicator organisms to any significant extent.

Finally, the investigation into distribution devices currently available in Ireland showed that they did not distribute the effluent effectively under real wastewater

[1] The T-value is the result of a standard falling-head percolation test used to determine the hydraulic assimilation capacity of the subsoil.

loading conditions from single houses. The on-site results suggested that the uneven deposition and biofilm growth were responsible for erratic distribution, and therefore the long-term performance and sustainability of such devices is questionable for such a function where regular maintenance is rarely carried out by house owners. However, a low-head gravity distribution device has been designed during the project which proved to operate effectively under such low intermittent flow rates of varying effluent quality. Finally the wastewater generation in the three sites was much lower than the EPA guidance value of 180 litres per capita per day: a value of 150 L c^{-1} d^{-1} would seem to be a more reasonable design figure.

1. Aims and Scope of the Research

1.1 Background

Groundwater is an important resource in Ireland, one which is under increasing risk from human activities, with contamination arising from both diffuse (generally agricultural) and point sources, particularly farmyards (manure and silage storage) and on-site wastewater treatment systems. Indeed, recent statistics (EPA, 2008) have shown that 36% of private group water schemes showed evidence of faecal contamination, with a much higher proportion expected for unregulated single-house well supplies. Domestic wastewater from over one-third of the population in Ireland is treated by on-site systems (DoELG *et al*., 1999), and with more than 25% of all water supplies provided by groundwater (EPA, 2005), the protection of groundwater resources from contamination by domestic wastewater effluent is imperative.

The national groundwater protection scheme is based on the concept of risk management using a hazard–pathway–target model, in which the hazard is the potentially polluting activity, the pathway is the subsoil described by the groundwater vulnerability and the target is the groundwater resource, generally assumed to be the aquifer, or a source such as a water supply well or spring (Misstear and Daly, 2000). The value of the different groundwater resources across Ireland has been categorised by the Geological Survey of Ireland into regionally important, locally important or poor aquifers. Source protection areas have also been delineated around large individual wells or springs used for water supply or industrial purposes. Moreover, the vulnerability of groundwater has been mapped and is based on a combination of the depth of subsoil above the aquifer and the subsoil permeability, and is divided into four categories: extreme, high, moderate or low. A matrix of vulnerability against resource or source protection area has then been defined as a Groundwater Protection Response for different land-use activities (DoELG *et al*., 1999), such as land spreading of sewage sludge, landfill sites and on-site treatment systems.

The EU Water Framework Directive (2000/60/EC) requires an integrated view of the water cycle and its components, whereby groundwater and surface water can no longer be viewed in isolation, but as components in the overall water balance of a river basin. Development and implementation of river basin district (RBD) management plans requires an understanding of the hydrological cycle and how human pressures may impact both groundwater and surface waters. Hence, risk assessments are needed for different generic pollutant sources, with on-site wastewater treatment systems having long been suspected as the cause of continuing contamination of both ground and surface water bodies. If the effluent loading on the subsoil is too high, the permeability of the subsoil excessive, or there is an insufficient depth of subsoil, then the groundwater beneath a percolation area is at risk of pollution, in particular from microbiological pathogens and/or nutrients. Alternatively, if there is insufficient permeability in the subsoil to take the effluent load, surface ponding may occur with associated health risks, and there will be a risk of effluent discharge/runoff of pollutants to surface water. The nutrient load in the effluent (either as direct discharge or from groundwater base flow) can contribute to eutrophication in sensitive water bodies, whilst contamination of water sources by human enteric pathogens can promote the outbreak of disease.

The Environmental Protection Agency's (EPA) guidance manual *Wastewater Treatment Manuals: Treatment Systems for Single Houses* (EPA, 2000) sets out an intensive site assessment procedure, comprising a desk study followed by an on-site visual trial hole inspection and percolation test in order to determine the vulnerability of local groundwater resources and identify receptors potentially at risk. The hydraulic assimilation capacity of the subsoil is determined from a standard falling-head percolation test. If the result (the so-called T-value) falls within the range 1 to 50 and there is a minimum unsaturated subsoil depth of 1.2 m below the point of effluent infiltration in the percolation area, then the site may be deemed suitable for on-site treatment of domestic wastewater effluent from a septic tank. Where subsoil T-values fall outside the recommended range, or the minimum unsaturated subsoil depth does not exist, the guidance advises that some form of secondary treatment process should be installed on the site, providing that there is 0.6 m of unsaturated subsoil for percolation of the secondary effluent. Such secondary treatment can be achieved using small-scale packaged treatment systems (RBC, SBR etc.) or systems built in-situ (sand filters, reed beds etc.). The EPA guidelines have been adopted by most local authorities and the document has recently undergone a significant revision en route to its status being enhanced to a regulatory Code of Practice, to replace the previous SR6 document (NSAI, 1991).

1.2 Aims and Objectives

The aim of the research project was to carry out a series of rigorous on-site trials in order to enhance the understanding of the processes involved and pollutant attenuation performance of relatively fast percolating subsoils (T-value < 5) receiving typical domestic on-site wastewater effluent. The project also studied the potential application of the horizontal subsurface flow reed bed process as treatment systems of such effluents. The third area of research was to investigate the efficacy of gravity flow distribution devices which should be used to split the on-site effluent evenly across a percolation area.

1.3 Characteristics of On-site Systems for Disposal of Wastewater Effluent

The septic tank treatment process involves domestic wastewater (excluding roof or road drainage) flowing into a two-chambered tank in which primary sedimentation occurs and also some anaerobic digestion. The effluent then overflows into a suitable soil percolation area where further physical, chemical and biological treatment processes occur. The prevailing anaerobic conditions in a septic tank provide limited treatment acting to breakdown and solubilise organics and nutrients. The effluent also can potentially contain high concentrations of pathogenic microorganisms (bacteria, viruses and protozoa) that are a particular threat to groundwater if used as a drinking water resource. In situations where a septic tank installation is not suitable, some form of secondary treatment system such as a packaged plant system or treatment process constructed in-situ (sand filter, reed bed etc.) may be installed to improve the quality of the effluent before discharge to the subsoil.

1.3.1 Subsoil Treatment Performance

The soil treatment system, comprising a series of percolation trenches beneath the surface which discharge effluent into the unsaturated subsoil, is a crucial component of the on-site wastewater treatment system. It must provide a sufficient contaminant attenuation zone in order to ensure long-term protection from groundwater pollution. The biogeochemical mechanisms for purification and hydraulic performance are complex and have been shown to be highly influenced by the biomat zone which forms at the soil–gravel interface along the base and wetted sides of the percolation trenches (Siegrist and Boyle, 1987; Beal *et al*., 2005). The biomat has generally been shown to have low hydraulic conductivities (Bouma, 1975) which can lead to effluent backing-up above the biomat, leaving conditions below unsaturated for aerobic degradation processes to operate on percolating effluent. The development of a biomat takes several months but will eventually reach a steady state equilibrium (Hillel, 1980) which the long-term acceptance rate (LTAR) – the basis of several design codes in Europe and elsewhere (CEN, 2005a) – attempts to define. Research has shown that greater than 90% removal efficiencies can be achieved under unsaturated subsoil conditions for BOD and SS by filtration, sorption and biodegradation processes, although the removal of nutrients can be more limited (Viraraghavan, 1976; Jenssen and Siegrist, 1990; Beal *et al*., 2005). Nitrification of septic tank effluent, however, is commonly reported in the unsaturated zone beneath the biomat (Pell and Nyberg, 1989; Van Cuyk *et al*., 2001). Equally, pathogens can be dramatically reduced through 0.6 to 0.9 m of unsaturated subsoil (Gerba *et al*., 1981; Kristiansen, 1981; Stevik *et al*., 1999; Van Cuyk *et al*., 2001, 2004). Most on-site research to date has been carried out in continental climates on sandy subsoils or under controlled laboratory conditions with little field research previously carried out in a temperate maritime climate or on the heterogeneous subsoils of north-western Europe. Hence, the findings can be difficult to extrapolate into an Irish context due to indeterminate percolation rates and different climatic conditions. Four separate sites with different subsoil permeabilities were studied in Ireland with the conclusions that the septic tank and percolation system provided a comparable treatment performance with respect to groundwater protection to the packaged secondary treatment system (Gill *et al.*, 2005). The secondary treated effluent discharged onto a percolation area did not appear to develop a significant biomat and hence the effluent was concentrated over a relatively small area compared to the septic tank effluent (Gill *et al.*, 2007).

1.3.2 Constructed Wetlands (Reed Beds)

A constructed wetland is an option for the treatment of on-site wastewater. The term is used to describe different categories of the generic process, differentiated according to media selection and the direction of effluent flow, as follows:

- Horizontal free surface flow constructed wetlands (with soil).
- Horizontal subsurface flow reed beds (with gravel).
- Vertical subsurface flow reed beds (with gravel or sand).

The most common type of reed bed is the subsurface horizontal flow reed bed with gravel as the chosen media where the wastewater is maintained below the surface of the media. Such reed beds are generally regarded as effective in terms of organics, suspended solids and pathogenic organism removal but will not nitrify any ammonia to nitrate due to oxygen limitations (Griggs and Grant, 2001; Vyzamal, 2002). Vertical flow reed bed systems are more effective than horizontal flow reed beds in not only reducing organics and suspended solid levels, but also in nitrifying ammonia nitrogen to nitrate. Hybrid reed bed systems, normally incorporating one or two stages of vertical flow followed by one or more stages of horizontal flow in series, may be designed to achieve higher treatment efficiency and in particular target total nitrogen removal, as well as organic reduction and pathogen removal. Free water surface based constructed wetlands need to be much larger than their subsurface counterparts to achieve the same level of treatment as the surface of the wastewater is at or above the surface of the soil support media. These systems however, can promote superior ecological diversity and aesthetics. There is a scarcity of reliable long-term performance data relevant to Ireland and its climate for such systems, and reluctance exists amongst some local authorities to permit the use of wetlands as stand-alone secondary treatment systems (Healy and Cawley, 2002).

1.3.3 Distribution Devices

Poor distribution of on-site wastewater effluent between parallel subsoil percolation trenches is often the cause of on-site wastewater system failures, resulting in hydraulic and biological overloading of one or more of the percolation trenches. Hence, equal distribution of the effluent is essential but can be particularly difficult to achieve when relying on the natural gravity flow of effluent to promote such a split. The EPA guidelines (EPA, 2000) assume equal distribution of the effluent between the requisite numbers of percolation trenches in order to attain the acceptable effluent loading rates, but little guidance is given on how to achieve such a split. In practice, the distribution of on-site effluent in Ireland is often achieved under gravity flow conditions using an *ad hoc* arrangement of standard sewer pipes; more recently though, specific distribution devices have become available on the market. Recent studies by Gill *et al.* (2004) on concrete distribution boxes in Ireland, however, showed a poor distribution performance which confirmed the need for longer term studies under real effluent loading conditions.

2. Site Description, Instrumentation and Analysis

2.1 Site Selection Criteria

All potential sites were investigated according to the EPA (2000) guidelines, with the additional requirement that the two sites for the project had to have percolation T-values of between 1 and 5, indicative of freely draining subsoil, and also a minimum depth of 2 m of unsaturated subsoil.

2.2 Test Sites

A total of 17 sites in eastern Ireland were formally investigated over the course of the project in order to settle on the two chosen research sites: Site A, near Clonard in Co. Kildare; and Site B, in Redcross, Co. Wicklow. In addition, a third site (Site C) was also selected in Riverchapel, Co. Wexford, to be used to investigate a packaged reed bed as a tertiary treatment system.

2.2.1 Site A: Kilrainy, Co. Kildare (T-value 3.7)

Site A lies within a region containing a variety of glaciofluvial sands and gravels, esker sands and gravels, and till derived chiefly from limestone. Bedrock mapping shows a mixture of pure bedded and unbedded Dinantian limestones, while the aquifer is classified as *locally important*. The 2.1 m deep trial hole showed a sufficient depth of unsaturated subsoil with a soil profile classified as sandy gravelly SILT from 1.0 m depth, down to sandy GRAVEL at 2.0 m depth. The two T-tests carried out on either side of the percolation area returned an average T-value of 3.7. For the duration of the project there were six people resident at Site A – a husband, wife and four sons.

2.2.2 Site B: Redcross, Co. Wicklow (T-value 4.5)

Site B lies over a till derived chiefly from Lower Palaeozoic rock. The bedrock is comprised of Ordivician metasediments, while the aquifer is classified as *locally important*. The 2.1 m deep trial hole identified the subsoil as sandy GRAVEL from 0.75 m down to the base of the hole. The two T-tests carried out on either side of the proposed percolation area both indicated relatively fast percolation rates (average T-value of 4.5). There were three people resident at Site B – a husband and wife, and her elderly mother.

2.2.3 Site C: Riverchapel, Co. Wexford

This site already had planning permission for a secondary treatment system and as the research focus here was merely to investigate the use of an additional packaged reed bed as a tertiary treatment process, no on-site assessment was required at this site. There were five people resident at Site C – a husband and wife, and three children, one of which was a newborn baby.

2.3 Site Layouts

A 3,785 litre two-chambered concrete septic tank was installed on Site A. The septic tank effluent (STE) was evenly split two ways via a distribution device – one half discharging into a set of three parallel percolation trenches, the other half into an horizontal flow (HF) reed bed constructed on site (Figure 2.1(a)). The effluent from the reed bed (RBE) was discharged to three parallel percolation trenches to provide further treatment in the underlying subsoil.

On Site B, the secondary treated effluent (SE) from a Klargester *Biodisc*® RBC treatment system, was split with half going to two parallel percolation trenches and the other half to a small HF reed bed constructed on site for tertiary treatment (Figure 2.1(b)). The wastewater treatment system on Site C comprised of a Klargester *Biodisc*® system for secondary treatment of the domestic effluent, followed by two prefabricated HF reed bed modules (Envirocare Pollution Ltd) in series, to act as tertiary treatment polishing filters (Figure 2.1(c)).

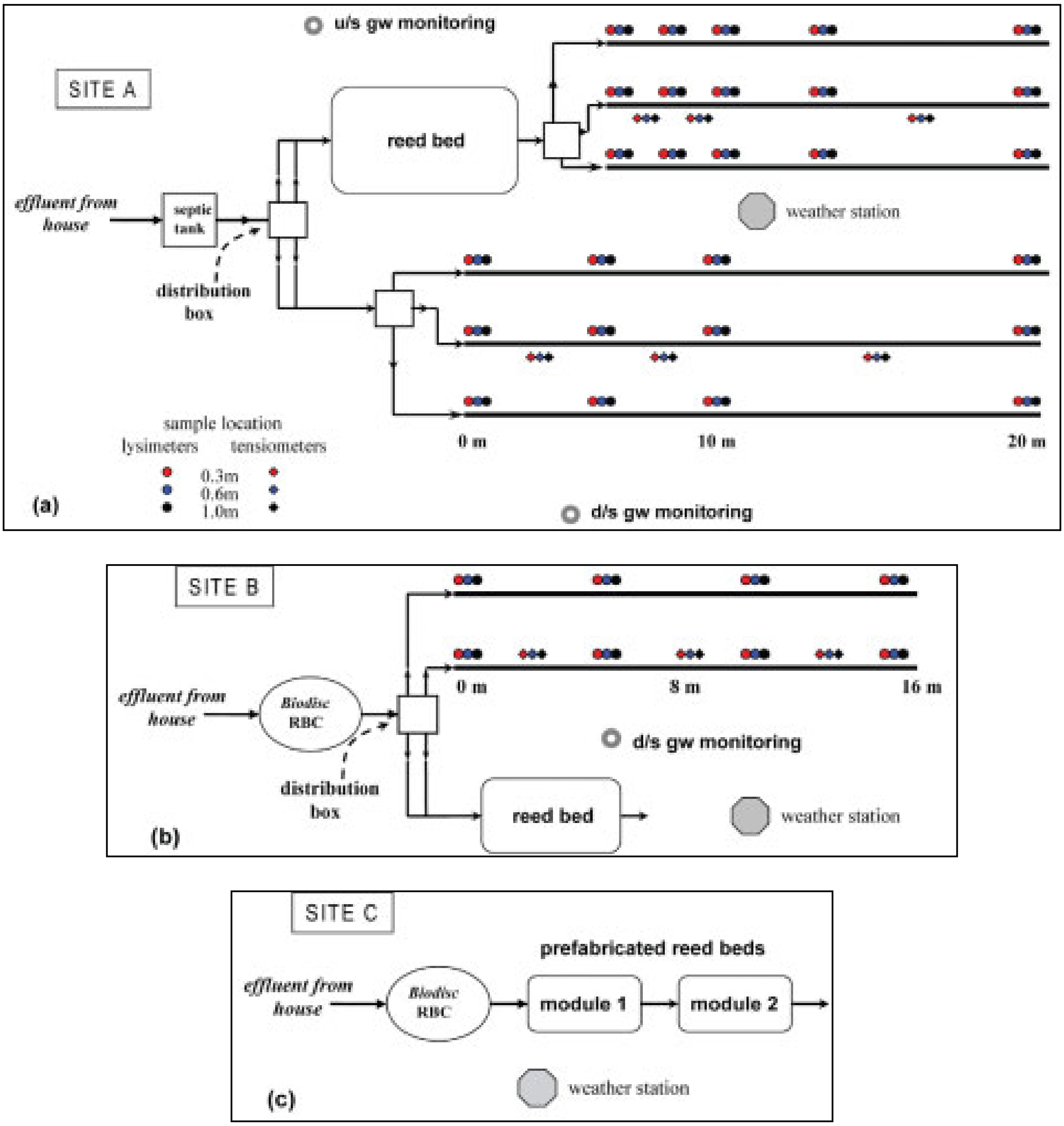


Figure 2.1. Plan and instrumentation layout of (a) Site A (Clonard), (b) Site B (Redcross), (c) Site C (Riverchapel).

2.4 Site Construction

2.4.1 Percolation Trenches

On Site A, the percolation trenches receiving STE were sized on a three-person hydraulic load since the total 6 population equivalent (PE) wastewater flow from the septic tank was split equally in two streams which resulted in 3 × 20 m length trenches (EPA, 2000). Similarly, for the percolation trenches receiving effluent from the secondary treatment reed bed, the recommended loading rate yielded 3 × 16 m length trenches. On Site B a total trench length 2 × 16 m length trenches were required for the percolation trenches receiving SE from the *Biodisc*® (based on a two-person hydraulic load).

2.4.2 Reed Beds Design and Construction

The HF reed beds in this project were designed on the basis of a plug flow, first-order kinetics model as widely adopted throughout Europe (Cooper *et al*., 1996; IWA, 2000). This yielded an area of 5 m^2 PE^{-1} for secondary treatment reed beds, with an average daily wastewater generation per capita of 180 L d^{-1} (EPA, 2000). Hence, the reed bed on Site A had a surface area of 15 m^2 (5 $m^2 \times$ 3PE) (Figure 2.2). The tertiary treatment reed bed on Site B had a surface area of 4 m^2 as per the minimum EPA sizing requirement. The bed depth was 0.6 m, giving overall dimensions for the secondary treatment reed bed on Site A as 5.8 × 2.6 × 0.6 m. A similar procedure was carried out for the tertiary reed bed on Site B, which produced dimensions of 4.0 × 1.0 × 0.6 m.

The reed beds were sealed with a single sheet of 1.2 mm thick butyl rubber liner as shown on Figure 2.3(a). The inlet pipework consisted of a tee-splitter and dual entry configuration to promote hydraulic distribution of the incoming wastewater in the bed. The outlet configuration consisted of a perforated pipe stretching the width of the bed (Figure 2.3(b)). The treated effluent discharged via a standpipe in a separate outlet sump. The discharge level on this standpipe was set to maintain the wastewater in the reed bed at a depth of 100 mm below the top surface of the bed. The bed was filled with washed pea gravel of 5–15 mm diameter to a depth of 0.6 m. At the inlet and outlet zones, 15–30 mm gravel was spread locally to improve effluent distribution. The two prefabricated reed bed modules on Site C were installed in series with module dimensions of 2.5 × 0.8 × 0.8 m. The first reed bed contained 20–30 mm washed gravel, whereas the second bed contained a "lacerite" media in order to investigate its potential to target phosphate adsorption. Both reed beds had a rooting zone depth of 600 mm for the growth of the emergent vegetation.

Wetland plants were planted in blocks of 4 per m^2 in the reed beds as follows: *Phragmites australis* on Site A (Figure 2.3(c, d)), a mixture of *Typha latifolia* and *Iris pseudacorus* on Site B (Figure 2.3(e)), and *Iris pseudacorus* and *Typha latifolia* in the first and second reed bed modules on Site C (Figure 2.3(f)).

2.5 Monitoring of On-site Wastewater Characteristics

The measurement of overall wastewater production and comparison of different flow rates split at each distribution device under realistic operational conditions was achieved by placing tipping bucket flow gauges underneath each of the four outlets. Diurnal and composite sampling on the septic tank, *Biodisc®* and reed bed effluents were carried out by automatic samplers at the three sites. In addition, samples were also taken across the centres of both monitored reed beds on Sites A and B where piezometers had been installed. These were used to determine the hydraulic conditions in the beds and assess the degree of short-circuiting and/or dead zones which might compromise the level of treatment with respect to the intended design.

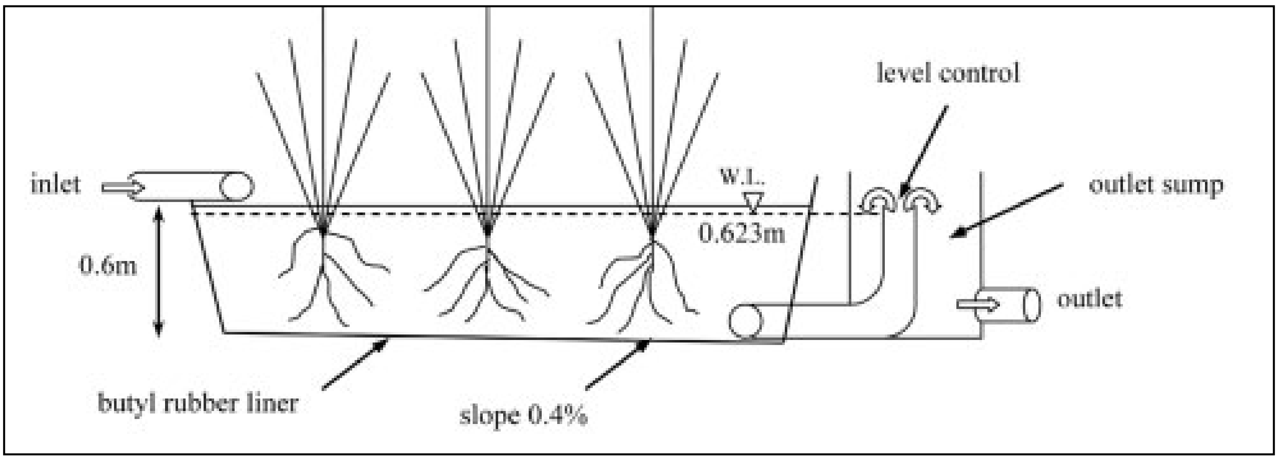


Figure 2.2. Schematic cross section through reed bed on Site A.

Figure 2.3. Construction of reed beds: (a) Insertion of liner, (b) Perforated submerged outlet, (c) Site A reed bed planted with *Phragmites sp.*, (d) Site A reed bed in September 2008, (e) Site B reed bed with *Typha* and *Iris sp.* in September 2008, (f) Site C reed bed modules with *Typha* and *Iris sp.* in September 2008.

2.6 Percolation Trench Monitoring

2.6.1 Suction Lysimeter Samplers

Three different length suction lysimeters were installed across the percolation area in trios at different depths – typically 0.35 m (red), 0.65 m (blue) and 0.95 m (black) below the invert level of the percolation trenches (see Figures 2.1 and 2.4(a)) – to allow periodic sampling of percolating effluent through the subsoil. A vacuum was created within the lysimeter using a pump to draw pore water from the soil matrix over the subsequent 24 hour period at which point the sample was collected.

2.6.2 Zero Tension Samplers

An alternative sampling technique using zero tension samplers (operating at ambient pressure) was used to provide a direct comparison against the suction lysimeters under identical effluent and subsoil conditions. Zero tension samplers were designed and manufactured in-house comprising a 1.85 m long stainless steel hollow tube with slot openings cut into the upper side of each tube and bordered either side by two steel fins to increase the local catchment area of percolating effluent. The samplers were installed to the same depth as the lysimeters as shown on Figure 2.4(b). The samplers were purged the day before sampling by pumping out any collected effluent, then left for a 24 hour period during which time they collected any percolate moving by gravity alone.

2.6.3 Tensiometers

Tensiometers were also installed across both percolation areas to determine the moisture status and pressure gradient at different depths within the soil profile in order to establish the extent of the biomat formation and areas of effluent percolation. A set of three tensiometers were positioned at distances of 2.5, 7.5 and 15 m along one of the trenches in each percolation area as shown on Figure 2.1, each trio comprising tensiometers 1.0, 1.5 and 2.0 m in length.

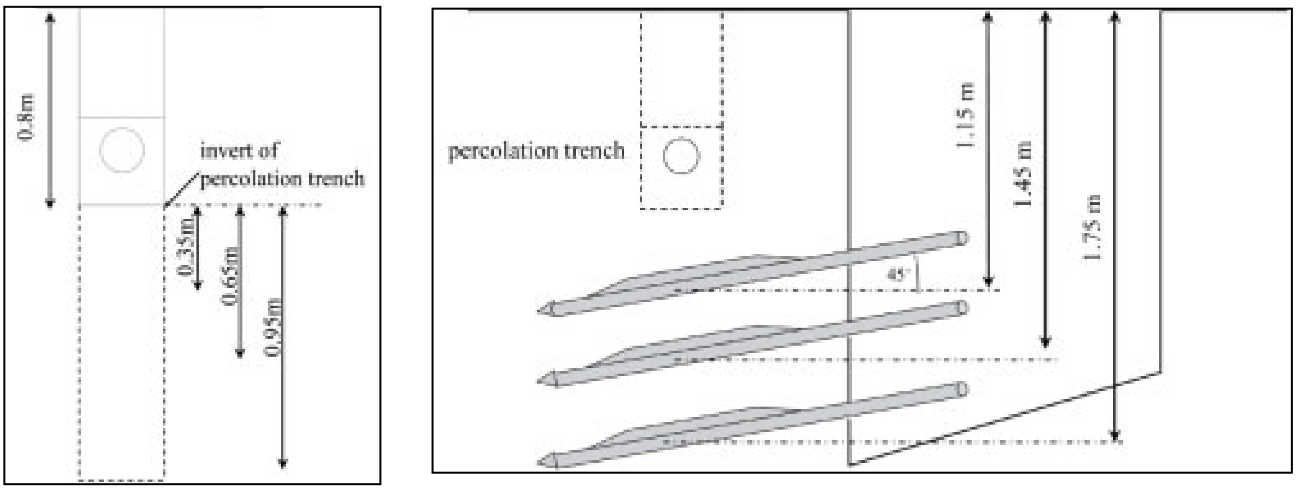
2.7 Meteorology Instrumentation

In order to assess the meteorological effects (evapotranspiration and precipitation levels) on the percolation areas and reed beds, weather stations (Campbell Scientific) and rain gauges (Casella) were installed on the sites. Parameters continuously recorded from the instrument were temperature, relative humidity, wind speed, wind direction, solar radiation and net radiation.

2.8 Analysis Methodology

2.8.1 Chemical Analysis

All septic tank, *Biodisc*®, reed-bed and soil-moisture samples were analysed for chemical oxygen demand (COD), total nitrogen, ammonium (NH_4-N), nitrite



(a) (b)

Figure 2.4. Cross section and typical depths of instrumentation: (a) Suction lysimeters, (b) Zero-tension samplers.

(NO_2-N), nitrate (NO_3-N), orthophosphate (PO_4-P), chloride (Cl), biochemical oxygen demand (BOD_5) and total suspended solids (TSS) using the methods described in the End of Project Report. Volatile fatty acid (VFA) analysis was also carried out on selected septic tank effluent samples. Bromide (Br^-) and Rhodamine WT (RWT) were used as tracers in the analysis of the subsoil and reed beds respectively. The measurement of the RWT in the reed bed effluent on both sites was via a calibrated submersible fluorometer inserted in the level control riser in the outlet sump.

Recent years have seen heightened interest into the investigation of a number of compounds that interfere with the normal action of the endocrine system, collectively known as endocrine disrupting chemicals, or EDCs (Damstra *et al*. 2002). Hence, specific samples were also analysed for natural steroid oestrogens (oestrone, 17β-oestradiol, synthetic ethynyloestradiol and oestriol), organic oxygen compound bisphenol A, and also caffeine (to investigate whether it can be used as a reliable indicator of domestic wastewater effluent).

In order to study the relative importance of the various nitrogen pathways and removal mechanisms in the reed beds, the influent to these systems were spiked with labelled ammonium chloride ($^{15}NH_4Cl$). The resulting levels of the $^{15}N/^{14}N$ ratios in both the suspended organic fraction and in solution (ammonium and nitrate) were then analysed by continuous flow-isotope ratio mass spectrometry (CF-IRMS). Equally, the uptake of phosphorus by the macrophytes in the reed beds was assessed by collecting representative samples of the reeds in Site A (*Phragmites australis*) and Site B (*Typha laitfolia* and *Iris pseudacorus*) at the end of the third season. Phosphorus extraction by acid digestion was carried out on samples of the stems and roots of respective reeds before concentrations were measured in an inductively coupled plasma (ICP) machine.

2.8.2 Bacteriological Analysis

All samples were tested for indicator bacteria of faecal contamination total coliforms (TC) and *E. coli* using the Idexx Colilert®-18 test with a semi-automated quantification method based on the Standard Methods Most Probable Number (MPN) model.

2.8.3 Bacteriophage Analysis

Three bacteriophages, MS2, φX174 and PR772, were used in this study as models for human enteric viruses, given the similarity with viral pathogens (see End of Project Report). All three bacteriophages were grown on their host *E. coli* lawns by the agar-overlay method, while enumeration of the phages was performed by the plaque forming unit (PFU) method.

2.9 Analysis of Gravity Flow Distribution Devices

A detailed analysis of different types of gravity flow distribution device, designed to split on-site wastewater effluent equally between percolation trenches, was carried out both in the laboratory and also in the field under real wastewater loading conditions. Several different types of distribution device have been compared: a V-notch distribution box, stilling chamber box and tee-splitters with and without baffles, swept tee bends and a new design based on tipping buckets.

Experiments were carried out in the laboratory on the distribution devices using potable water at various flow rates ranging from 0.5 to 12 L min^{-1}. The flow was supplied to the distribution device by a 110 mm diameter pipe placed at a slope of 1 in 60 fed in order to imitate actual conditions on-site as recommended in the guidelines (EPA, 2000). The sensitivity to off-level installation angles was tested at five different inclination angles of 0° (no tilt), 1°, 2°, 3° and 5°. The volume of water collected from each outlet was normalised with respect to the total volume for a particular flow rate and then the standard deviation (SD) was calculated based on the percentage flow through each outlet. The SD was then calculated from the four percentages (outlets) for each flow rate and inclination angle experiment. Acceptable distribution was arbitrarily taken as SD = 5, which equates, for example, as the following percentage volume collected at four outlets – 22%, 27%, 20% and 31%.

The different distribution devices were also installed in turn for sequential six month trial periods at both Site A and B. Each distribution device was monitored in terms of its distribution efficiency of the incoming gravity flow effluent under realistic operational conditions by placing a tipping bucket flow gauge (model 6506H-Unidata, Australia) recording onto a *Starlog* data logger underneath each of the four outlets (see Figure 2.5). In all cases particular attention was taken to ensure that the distribution devices were installed exactly level. The level was checked throughout the trial period on every subsequent visit to ensure that this did not change due to settlement or disturbance. The weirs in all the distribution devices were cleaned at the end of every month trial period to standardise comparisons between the different devices. However, during the final period when the optimized devices were on trial (February to June 2008) no cleaning took place to assess the sustainability and robustness of the devices.

Figure 2.5. Tipping bucket flow gauge instrumentation in place on Site B.

3. Research Outcomes

3.1 On-Site Wastewater Production and Characteristics

3.1.1 Hydraulic Regime

The on-site wastewater production on the sites continuously measured over two years showed effluent production statistics of 119.4, 89.6 and 130.2 L c^{-1} d^{-1} on Sites A, B and C respectively. Hence, this reveals that the assumption of 180 L c^{-1} d^{-1} in the Irish EPA guidelines (EPA, 2000) appears to over-predict significantly the average wastewater production in such one-off dwellings with typical sized family units. This also matches data recorded in previous studies on four other continuously monitored sites (Gill *et al.*, 2005). The 180 L c^{-1} d^{-1} design figure is a value typically used for urban wastewater statistics where it is usual for people to live and work within the same drainage network. Hence, a full day's wastewater from each person is discharged into the same system, albeit at different points on the network. For on-site wastewater, however, the residents will spend a good percentage of the day outside the on-site "catchment" (i.e. the house) and thus some of their daily wastewater production will go into other systems (catchments). It should also be noted that average water consumption (and by inference, wastewater production) in Ireland is less than 150 L c^{-1} d^{-1}.

3.1.2 Wastewater Characteristics – Septic Tank

In general, the effluent concentrations of most of the water quality parameters from the septic tank were fairly high when compared to the typical influent concentrations outlined in either EPA (2000), or the CEN 12566 European standards (CEN 2005b, c). Again, this matches the results from previous studies on septic tanks at four other sites (Gill *et al.*, 2005). The anaerobic environment of the septic tank, operating at an average hydraulic retention time of approximately six days over the course of the project, facilitated the conversion of organic nitrogen into inorganic ammonium and also the production of VFAs, mainly in the form of acetic acid. There were seasonal trends in the COD, ammonia and (to a lesser extent) phosphate concentrations due to temperature changes, with the warmer periods in the summer promoting faster anaerobic activity in the tank. Although the septic tank was not desludged throughout the entire trial, a period of 32 months, there did not appear to be any long-term trend in the effluent concentrations over the sampling period.

3.1.3 Wastewater Characteristics – RBC Package Plants

The RBC effluent on Site B consistently discharged relatively high organic concentrations for secondary treated effluent, and the process only acted to partially nitrify the effluent. Total coliforms and *E. coli* were detected at consistently high levels in the RBC effluent, but were 1.5 to 2 $\log_{10}$ less than the equivalent concentrations measured in the STE on Site A. The sensitivity of the process to regular maintenance was evident after around 18 months of operation without desludging the system, when the sludge blanket in the final clarifier started lifting, creating high solids concentrations in the final effluent. Counter-intuitively perhaps, the RBC on Site C performed much better as an on-site secondary treatment process than the unit on Site B, even though it received almost three times the hydraulic loading, discharging a fully nitrified effluent with low organic concentrations. The phosphate concentrations in the effluent were relatively low, although increased as the trial progressed, presumably due to the build up of sludge in the anaerobic conditions of the primary tank. Total coliforms and *E. coli* were detected at levels 1 to 2 $\log_{10}$ lower than the Site B RBC effluent, but still at levels which required further treatment prior to discharge to groundwater.

3.2 Comparison of Subsoils

Both percolation areas on Sites A and B had been receiving effluent for at least 32 months by the end of the trials. This time period was considerably longer than the research carried out on percolation areas previously in Ireland, which allowed the development of the biomat over such a longer time frame to be monitored.

3.2.1 Trenches Receiving Septic Tank Effluent

The biomats on the two intensely monitored trenches had spread to 8 and 11 m respectively after approximately six months of operation, and did not appear to have spread any further in the subsequent two years of monitoring. The majority of the COD load was removed in the first 0.35 m of unsaturated subsoil and overlying distribution gravel, with COD concentrations approaching background level beneath this. Similarly, nitrogen analyses showed that the greatest reduction in total nitrogen loads occurred above 0.35 m of unsaturated subsoil, which was attributed to be mainly due to nitrification followed by rapid denitrification in localised micro-sites where saturated conditions are prevalent. The majority of PO_4-P removal from the STE effluent also occurred within the first 0.35 m of unsaturated subsoil, which was attributed to adsorption to the clay fractions in the subsoil at this depth. However, towards the end of the 32 month trial period there was perhaps a slight increase in phosphorus concentrations with depth, indicating that the limited adsorption sites were starting to become saturated. The high purification capacity of the biomat and 0.35 m thickness of underlying unsaturated subsoil provided 99.99% reduction removal in total coliforms by a depth of 0.35 m, and showed almost complete removal of indicator enteric bacteria (*E. coli*) within the system after a depth of 0.95 m, with the exception of a few isolated incidences of faecal contamination at low concentrations.

3.2.2 Trenches Receiving Reed Bed Effluent

The spread of the biomat on the two intensely monitored trenches receiving RBE was only 6.5 m after two years, owing to the reduced organic load to the trenches compared to the parallel trenches receiving STE. Removal of organics, nitrogen and phosphorus with percolated depth was similar to the trenches receiving STE with most removal occurring within the first 0.35 m of unsaturated subsoil. Total nitrogen levels at the 0.95 m depth plane were seen to be very similar to the equivalent loads measured at the same depth under the percolation trenches receiving STE. The resultant impact on localised groundwater quality was evident in the shallow borehole just downstream of the percolation area, which showed nitrate concentrations at similar elevated levels throughout the project. The greater effluent percolation rate and thus reduced purification capacity in such highly permeable subsoil was most probably the key factor in the poor reduction in nitrogen loads. Analysis of the fate of enteric bacteria in the trenches receiving RBE showed maximum removal again to occur in the first 0.35 m of unsaturated subsoil, although only at half the removal (2 $\log_{10}$) achieved in the equivalent depth under the trenches receiving STE. This suggests that increased biomat development facilitates significant retention of the bacteria prior to subsoil treatment. A number of incidents of faecal contamination were detected at the minimum discharge point to groundwater – the 0.95 m depth plane – at higher concentrations than beneath the parallel trenches receiving STE, despite a reduced microbial loading on the trenches. This again shows the effect of increased hydraulic loading on the trenches receiving RBE due to the muted biomat development.

3.2.3 Trenches Receiving Packaged-Plant Effluent

The spread of the biomat on the two trenches receiving *Biodisc®* effluent was less than 0.5 m after two years, much reduced compared to the biomat spread on the trenches receiving STE and reed bed effluent on Site A. Over two-thirds of the organic load removal occurred in the subsoil above the red depth plane (i.e. the first 0.35 m of subsoil) or within the distribution gravel, with little further reduction with increased depth as the COD concentrations approached background levels. The secondary effluent from the *Biodisc®* underwent complete nitrification within the first 0.35 m of subsoil, but there was no parallel reduction in total inorganic N loading in the percolate over the same subsoil thickness as had been observed on Site A, or any evidence significant denitrification with increased subsoil depth. It is surmised that the heterotrophic denitrifying bacteria would have been inhibited due to the very low organic loads in the subsoil in addition to the fact that rapid infiltration of the secondary treated effluent in the highly permeable soil would have maintained unsaturated aerobic conditions. Significant enteric bacterial reduction was achieved within the system, with the majority again in the first 0.35 m of subsoil. Nevertheless, there was evidence of faecal contamination with depth on a proportionally similar number of incidences to those recorded beneath the trenches receiving STE on Site A, despite the lower bacterial load in the secondary treated effluent. This was due to a combination of the coarse textured subsoil in the unsaturated zone facilitating the undisturbed movement of bacteria through the subsoil, compounded by the poor biomat development acting to increase the hydraulic load per unit area thus compromising treatment capacity.

3.2.4 EDCs

The removal of oestrogens with depth through the subsoil was found on both sites, with all oestrogens degraded down to very low values with depth, with the exception of oestriol which seemed to be more persistent. The results from the bisphenol A sampling showed that only about half of the EDC was removed underneath the septic-tank effluent trenches, contrary to the received wisdom that it would have been subject to biodegradation and adsorption whilst percolating through the subsoil.

3.2.5 Bacteriophages

The bacteriophage spiking trials on Site A showed that by the time the percolate had reached the black depth plane all three phages (MS2, PR772, φX174) had been reduced to their minimum detection limit – a mean phage removal of at least 3 $\log_{10}$ units over an unsaturated subsoil depth of 0.95 m. However, whilst the greatest removal of MS2 was over the initial 0.35 m of subsoil below the infiltrative surface of the trenches receiving STE, high concentrations of φX174, in particular, and PR772 were still detected at this depth, which was attributed to the presence of organic matter in the shallower subsoil depths beneath the trenches which could inhibit virus sorption by blocking or impeding the pathways to sorption sites. Once through the biomat zone, the unsaturated conditions in the deeper subsoil would then mean that viruses passed close to the soil particles, increasing virus adsorption and thus removal.

The bacteriophage trials beneath the trenches receiving SE on Site B highlighted a much more rapid travel time for the percolating effluent, owing to a combination of the poor biomat spread and the resultant high hydraulic loading rate. Initial removal of all three phages, MS2, φX174 and PR772, over the first 0.35 m was found to be similar, and subsequent attenuation over the remaining 0.6 m depth of subsoil resulted in all three undergoing greater than 99.5% removal. The more uniform removal of all three phages with depth indicated consistent adsorption to the soil particles under unsaturated conditions. However, low concentrations of both MS2 and PR772 were detected after an unsaturated subsoil depth of 0.95 m, which highlights a potential risk of viral contamination to an underlying aquifer.

3.3 Comparison of Reed Beds

In general, the performance of the horizontal subsurface flow reed beds for both secondary and tertiary treatment performed much according to international literature: i.e. reasonable organics and enteric bacteria removal but less impressive with respect to nutrient removal. The phosphorus uptake by the reeds was shown to be minimal with respect to phosphorus loading in the effluent and virus and EDC removal was generally poor through the beds.

3.3.1 Horizontal Subsurface Flow Gravel Reed Bed for Secondary Treatment

The reed bed did not make a significant difference to the flows going to the percolation trenches, acting to increase flows by 13.5% on average in winter while just about balancing the evapotranspiration in the summer. Tracer studies indicated that the bed seemed to be acting hydraulically more or less as designed, with the full volume of the bed actively treating the effluent, i.e. no significant dead zones or short circuiting. When compared to the hydraulic loading rate (HLR) design values recommended in EPA (2000), the secondary treatment reed bed was over-designed by a factor of 1.66 times, owing to the lower than anticipated on-site hydraulic loads.

Treatment provided by the reed bed resulted in a 67% reduction in organic load and 77% removal of suspended solids on average, with improving trends in treatment performance over time. On a seasonal basis, there appeared to be no additional degradation of organics in summer, suggesting that, in a temperate climate such as Ireland’s, temperature does not play a major role in the kinetics of the system. Nutrient removal, as expected, was found to be not so impressive, with only 29% removal of total N. The results of the ^{15}N isotope tracer study confirmed that over one-third of the ammonium from the septic tank was passing straight through the reed bed without taking part in any biogeochemical processes, whilst the rest of the ammonium had been taken onto organic form and then released again as soluble ammonium – an example of so-called nitrogen "spiralling" in wetlands. The average removal of PO_4-P though the reed bed was 45%, which was attributed to plant uptake, adsorption and microbial immobilisation. However, the results from analysing the phosphorus in the biomass after a full year's growth showed that if the annual above ground stem matter was completely removed it would account for only 8.4% of the annual total P-load to the reed bed. It should also be noted that the effluent PO_4-P concentrations were still found to be high (> 8 mg/l on average). Removal rates in TC and *E. coli* through the reed bed were similar at 1.8 $\log_{10}$ and 1.4 $\log_{10}$ respectively, although with concentrations ranging from 3×10^3 to 2×10^6 MPN 100 mL^{-1} still remaining in the discharging effluent, further bacteriological treatment of the effluent would be a prerequisite prior to discharge to groundwater. The results of bacteriophage tracing trials on the Site A reed bed showed a generally poor removal/inactivation of the three phages over the six to seven days retention in the reed bed environment.

3.3.2 Horizontal Subsurface Flow Gravel Reed Bed for Tertiary Treatment

The smaller tertiary treatment reed bed on Site B did not make a significant difference to the flows going to the percolation trenches, acting to increase flows by 5.2% on average in winter and 0.8% in summer. The tracer studies showed that the full volume of the reed bed was receiving the active flow with no short-circuiting or dead zones. Again, the reed bed was over-designed by a factor of 2.6 times when compared to the respective HLR design values recommended in the EPA guidelines, owing to the lower than anticipated on-site hydraulic loads.

Treatment provided by the reed bed resulted in a 55% reduction in COD load from the applied SE with a slightly improving performance trend over time. Total N load removal (30%) was poor, especially given that the influent to the process had been partially nitrified in the RBC package plant. The results of the ^{15}N isotope tracer study confirmed that approximately only 18% of the spiked ^{15}N passed straight through the reed bed and that the rest of the isotope had been taken up by the plants or lost by other means (denitrification etc.). Hence, these recovery rates indicate that approximately half of the influent N is taken up by the plants at this time of year. Again, a poor load removal in PO_4-P (22%) was measured across the reed bed, resulting in high average effluent concentrations of 23 mg L^{-1}. These were significantly greater than concentrations in the reed bed effluent treating STE on Site A, probably due to a combination of reduced surface area for adsorption, a greater average HLR and lower organic loading to the bed. The results from analysing the *Iris* and *Typha* reeds after a full year's growth show that the phosphorus in the living roots and stems accounted for only 1.3% of the phosphorus load to the reed bed. A comparison between the different reeds with respect to the average phosphorus concentration in the biomass revealed that *Phragmites* contained more phosphorus accessible for harvesting above the ground in its stems and leaves. However, the concept of harvesting the reeds at the end of every growing season for the purpose of removing the phosphorus has been shown to be of limited effect from these studies. There was a 1.6 $\log_{10}$ removal of enteric indicator bacteria through the tertiary treatment reed bed, measured as *E. coli*, but with a mean concentration of 2.4×10^2 MPN 100 mL^{-1} still remaining in the discharging effluent, further bacteriological treatment of the effluent would be essential prior to the effluent reaching the groundwater. Similar to the Site A reed bed, low phage removal rates for MS2 and φX174 were recorded through the Site B reed bed. However, removal rates for PR772 were also found to be poor, which was attributed to the cleaner effluent in the tertiary treatment reed bed, being low in organics, doing little to prevent significant transport of PR772 to the outlet.

3.3.3 Packaged Horizontal Subsurface Flow Gravel Reed Bed for Tertiary Treatment

The two packaged tertiary treatment reed bed modules removed approximately half the organic load from the applied SE. However, overall total N load removal (12%) was unexpectedly poor, especially as the influent was totally nitrified. This was attributed to the lower retention times in the modules as, unlike the reed beds on Sites A and B, they were experiencing hydraulic loading rates of over twice the recommended values in the EPA guidelines. PO_4-P load removal was found to be 45% across the reed bed, although effluent PO_4-P concentrations were found to be relatively high at an average of 6.0 mg L^{-1}. PO_4-P concentrations over the duration of the trial showed a distinct drop in performance after 18 months as inlet concentrations in P start to rise, which indicated the limited effectiveness of the *lacerite* media in the second reed bed specifically to target phosphorus removal. An 0.8 $\log_{10}$ removal of enteric indicator bacteria, *E. coli* was measured across the two reed beds, but with a mean concentration of 1.2×10^2 MPN 100 mL^{-1} still remaining in the discharging effluent, further bacteriological treatment of the effluent would be essential prior to groundwater infiltration.

3.3.4 EDCs

There appeared to be little or no degradation of oestrogens or bisphenol A under the anoxic/anaerobic conditions in the reed beds, confirming other research. This shows that most oestrogen removal in the on-site treatment environment must be due to aerobic biodegradation and not sorption, as there would be plenty of opportunities to sorb to organic particles in the wetlands.

3.4 Comparison of Distribution Devices

The laboratory tests on several distribution devices showed that the flow splitter devices performed the best of the commercially available devices, although level installation was obviously a critical factor for all devices, as was the prevention of differential settlement. Equally, the performance of these devices all dropped off at low flow rates (< 2 L min^{-1}), which are the normal flow conditions from single-house wastewater systems. The most common flow rates experienced at the distribution devices on the research sites were in the form of intermittent, small-volume pulses between 0.1 to 1 L min^{-1}. Standard pipe connectors found in builders' suppliers were also investigated as they are known to be commonly used on site to distribute effluent. These performed extremely poorly whether installed level or not, indicating that the likely effluent distribution at numerous on-site wastewater treatment systems across the country must be extremely poor.

Tests under real effluent conditions on both Sites A and B were carried out with the distribution devices installed exactly level and also cleaned at the end of every month trial period to standardise comparisons between the different devices. The overall performance of the V-notch devices on site was marginally better than the stilling chamber or T-splitters. However, the on-site performance of all these gravity distribution devices was still poor, even under such a regular cleaning regime, due to uneven solids deposition and biofilm growth being responsible for erratic distribution. There was no particular improved performance of the devices with the cleaner secondary treated effluent compared to the septic tank effluent as may have been expected, rather it was the flow rate which seemed to be important in terms of keeping the weirs clear of solids for longer periods. The trials suggest that regular maintenance would be required to achieve anywhere close to an even effluent distribution using such devices. These trials clearly showed that there was a need for the design of a robust low-head gravity distribution device which can operate effectively under such low intermittent flow rates of varying effluent quality. A new distribution device was duly developed by the project team which combined the use of a low-head tipping bucket with vertical fins. This design demonstrated an excellent performance under laboratory conditions, being less sensitive to off-angle installation than other devices, and then proved to have a constant acceptable level of distribution between four outlets over a four month continuous trial on Site B without any maintenance under low flow influent conditions.

These trials clearly demonstrated the importance of assessing the performance of distribution devices under realistic effluent loading (both flow and quality) conditions on site. These trials also show that it is reasonable to assume that poor effluent distribution is occurring at most sites across the country due to inappropriate devices, off-level installation or lack of maintenance. It follows that most percolation areas must be sections that are overloaded, creating a potential threat to both groundwater and surface water resources.

4. Conclusions and Recommendations

4.1 Conclusions

- The septic tank and percolation system provided a comparable treatment performance with respect to groundwater protection to the packaged secondary treatment system on subsoils with relatively fast percolation characteristics (T values 3.7 and 4.5), with the exception of nitrogen and viral indicators which underwent enhanced attenuation in the subsoil receiving septic tank effluent.
- The higher permeability subsoil acted to reduce the biomat lengths and thus increase the areal effluent loading rate on the percolation areas. The biomat length for the trenches receiving septic tank effluent was roughly 10 m, compared to the biomats in the percolation trenches receiving package plant secondary treated effluent which were considerably shorter and did not extend beyond 0.5 m. The biomat lengths for all trenches were quickly established during the first few months of receiving effluent, after which point they appeared to reach a state of equilibrium.
- The majority of the treatment of the percolating effluent took place in the distribution gravel and first 300 mm of subsoil. Phosphorus removal from the percolating effluent on both sites was very high within the first 300 mm of subsoil and was attributed to the presence of clay particles.
- The nitrogen loads in the septic tank effluent were 49% removed after 0.95 m of subsoil depth, compared to a value of only 11% removal on the subsoil receiving package plant secondary treated effluent.
- Although 0.95 m of unsaturated subsoil significantly reduced the enteric bacteria in the septic tank effluent, reed bed effluent and secondary treated effluent, there were isolated incidences of low concentrations of *E. coli* found in the subsoil on both sites at this depth.
- The use of three different bacteriophage tracers (MS2, φX174, PR772) on the sites indicated that enteric viruses in on-site wastewater effluent are likely to be totally removed after a depth of 0.95 m of unsaturated subsoil underneath trenches receiving septic tank effluent. However, some phage concentrations were still detected after 0.95 m depth of unsaturated subsoil beneath percolation trenches discharging secondary treated effluent at a much higher hydraulic loading rate. Hence, the required depth of subsoil should be increased beyond this depth for high permeability subsoil at least.
- The horizontal flow subsurface reed bed designed as a secondary treatment process on an aerial loading rate of 5 m^2 per person was effective at reducing organic, suspended solids and bacteriological loads but not nutrients or bacteriophages. The process produced an effluent quality that was similar to the poorly performing RBC system on Site B, without nitrifying the effluent. The reed bed also acted to slightly enhance the hydraulic loading over the course of a year in an Irish climate.
- The horizontal flow subsurface reed beds acting as tertiary treatment systems on Sites B and C achieved further polishing of the secondary effluent in terms of organics and enteric bacteria and some removal of nutrient loads. The microbiological quality of the final effluent, however, still contained significant numbers of human enteric bacteria and the beds did not act to attenuate viral indicator organism to any significant extent.
- The concept of harvesting the reeds at the end of every growing season as a mechanism of sustainable phosphorus removal has been quantified and shown to be very limited – at best less than 10% of the typical on-site phosphorus loads.
- The current distribution devices available in Ireland or *ad hoc* methods of combining sewer pipes do not distribute the effluent effectively. The on-site results for the other commercially available

distribution devices suggested that the uneven deposition and biofilm growth were responsible for the erratic distribution and therefore the long-term sustainability of such devices is questionable for the on-site arena where regular maintenance is rarely carried out by house owners. However, a low-head gravity distribution device has been designed which can operate effectively under such low intermittent flow rates of varying effluent quality.

- The wastewater generation in the three sites was much lower than the EPA guidance value of 180 L c^{-1} d^{-1}: a value of 150 L c^{-1} d^{-1} would seem to be a more reasonable design figure as an upper limit.

4.2 Recommendations for EPA Policy

- This study has shown that the discharge of septic tank effluent or packaged plant secondary treated effluent onto gravity fed percolation areas with subsoils of relatively quick percolation characteristics (T-values down to 3.5) provides a reasonable protection to groundwater, providing there is at least 0.95 m of unsaturated subsoil. However, secondary treated effluent discharged into such subsoils results in a much reduced biomat with equivalent increases in the hydraulic loading. This seems to promote a higher nitrogen load on the groundwater and also there was evidence of breakthrough of the indicator bacteriophages. Hence, packaged plants should not be promoted over septic tanks in areas where the reasonable unsaturated subsoil depths and percolation rates exist.

- The effects of increased percolation in these sites with relatively fast percolation characteristics compared to previous studies on higher T-value sites is evident – muted biomat development and reduced nitrogen removal on the percolation area receiving septic tank effluent, and isolated incidences of bacterial breakthrough of *E. coli* under trenches receiving both septic tank and secondary treated effluent. Hence, it is recommended that the current lower T-value limit for fast percolating subsoils of T = 1 should be raised to T = 3 on a precautionary basis.

- The use of three different bacteriophage tracers on the sites has demonstrated that enteric viruses in on-site effluent should be almost completely removed with 0.95 m of subsoil. However, as small concentrations were still detected after 0.95 m beneath the trenches receiving secondary treated effluent, the trials confirm the decision to increase the depth of subsoil required in the new Code of Practice from 0.6 to 0.9 m for percolation areas receiving such effluent.

- The minimal spread of the biomat on the trenches receiving secondary treated effluent means that consideration should be given on such sites as to how to distribute the effluent over a wider area for percolation, as the majority of the trench in the current design is not being used.

- The design criteria given for horizontal flow reed beds in the forthcoming Code of Practice are appropriate for both secondary and tertiary systems, although the limitations of the systems need to be acknowledged. The effluent from tertiary treatment reed beds will still need to pass through a polishing filter before discharging to groundwater.

- The project has highlighted that maintenance requirements are important on a regular basis, especially for packaged plants and distribution devices, which is a message that should be heavily reinforced in the forthcoming Code of Practice. The existing distribution devices on the market are not suitable for use in gravity fed on-site situations without regular maintenance.

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List of Acronyms

BOD	biochemical oxygen demand
CV	coefficient of variation
EDC	endocrine disrupting chemical
ERF	effective rainfall
HF	horizontal flow
HLR	hydraulic loading rate
HRT	hydraulic retention time
MPN	most probable number
PE	population equivalent
PFU	plaque forming units
RBC	rotating biological contactor
RBE	reed bed effluent
RWT	Rhodamine WT
SBR	sequencing batch reactor
SE	secondary treated effluent
SMD	soil moisture deficit
SS	suspended solids
SSF	subsurface flow
STE	septic tank effluent
VFA	volatile fatty acid

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.
- Scardadh dramhuisce

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

NDP
National Development Plan 2007 - 2013

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

epa
Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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SSTI
Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government