Nitrogen loading on groundwater from the discharge of on-site domestic wastewater effluent into different subsoils in Ireland

L. W. Gill, C. O’Suilleabhain, B. D. R. Misstear, P. Johnston, T. Patel and N. O’Luanaigh

ABSTRACT

The performance of six separate percolation areas has been intensively monitored to ascertain the attenuation effects of the unsaturated subsoil with respect to on-site wastewater effluent. Septic tank effluent on three sites and secondary treated effluent on the other three sites was discharged into subsoils of varying percolation values. Samples of the percolating effluent were taken using suction lysimeters installed to nominal depths of 0.3, 0.6 and 1.0 m below the invert of the percolation trenches. The results clearly showed that the development of a biomat across the percolation areas receiving secondary treated effluent was muted on these sites compared to the sites receiving septic tank effluent. Significant differences were found between the sites receiving septic tank and secondary treated effluent in terms of the potential nitrogen loading to groundwater. The average nitrogen loading after 1.0 m depth of unsaturated subsoil per capita equated to 5.5, 3.3 and 3.2 gTotal-N/d for the sites receiving secondary treated effluent compared to 4.2, 1.7 and 0.3 gTotal-N/d for the sites receiving septic tank effluent. The noticeably higher nitrogen loading on one of the septic tank sites corresponded to the effluent percolating through highly permeable subsoil that counteracted any significant denitrification.

Key words | nitrogen, on-site wastewater, septic tank

INTRODUCTION

Groundwater is an important resource in Ireland which is under increasing risk from the spread of burgeoning numbers of decentralized houses and their respective on-site treatment systems. In Ireland, domestic wastewater from over one third of the population is treated by on-site systems (Department of the Environment 2004) 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 percolation area (soil absorption system) is an integral part of the overall on-site system, particularly since the main aquifers in Ireland occur in fissured or fractured bedrock formations overlain by subsoils of variable thickness and permeability. Groundwater needs to be protected from nitrogen pollution for both ecological reasons (nutrient enrichment of sensitive surface waters) and health based reasons due to the link between nitrate concentrations and methemoglobinemia (“blue-baby syndrome”), increased incidence of cancer, adverse reproductive effects, and other possible effects. There is increasing scepticism, however, as to the link between drinking nitrate in waters and methemoglobinemia due to the generally poor correlation between drinking-water nitrate and blue-baby syndrome and that fact that such infant deaths are now almost unheard of in the U.S. and countries of Western Europe despite the fact that drinking water from private

wells with high nitrate levels continues to be extensively used in these countries (L’hirondel & L’hirondel 2002). Other theories such as “endogenous nitrate/nitrite production” have been put forward (Ward et al. 2005) and an emerging view is that contamination of well-water with infectious microorganisms, rather than nitrate, may be the primary cause of blue-baby syndrome (Avery 1999).

A septic tank acts primarily as a settlement chamber providing quiescent, anaerobic conditions that facilitate the reduction of the organic and suspended solids content of wastewater. However, the environment within the septic tank is largely ineffective in reducing the nutrient loading of the wastewater, acting only to convert the influent organic N to NH₄ and the organic P to inorganic P (Lawrence 1973; Canter & Knox 1985; Beal et al. 2005). A secondary treatment system can be installed as an alternative to a septic tank or to provide subsequent treatment of septic tank effluent (STE) prior to discharge to subsoil. Secondary treatment systems in the form of mechanical aeration systems, filter systems or constructed wetlands, provide a controlled aerobic environment for the accelerated biodegradation processes, although the removal of nutrients can be more limited (Jenssen & Siegrist 1990; Van Cuyk et al. 2001; Beal et al. 2005). Nitrification of STE however, is also commonly reported in the unsaturated zone beneath the biomat (Pell & Nyberg 1989; Van Cuyk et al. 2001). Other studies have shown that denitrification of percolating nitrates in soils tends to occur more readily in fine-textured soils (i.e. clays and silt/clays) compared to coarse-textured soils (silt and sands) (Tucholke et al. 2007).

On-site wastewater effluent in Ireland is typically discharged to ground via a number of parallel percolation trenches. For a site to be deemed suitable the subsoil must have a percolation value equivalent to a field saturated hydraulic conductivity in the range 0.08 to 4.2 m d⁻¹ using a standardised falling head percolation test (Mulqueen & Rodgers 2001; CEN 2006). A minimum of 1.2 m of unsaturated subsoil must also exist below the invert of the percolation area receiving effluent from a septic tank or 0.6 m if the effluent has undergone secondary treatment in a packaged system. Two sequential three-year projects funded by the EPA have been undertaken to test out the efficacy of these recommendations on a range of sites with subsoils of different percolation characteristics receiving domestic wastewater effluent.

METHODS

Site selection and construction

Six sites located in Counties Kildare and Wicklow were studied for the projects–three sites receiving STE and three sites receiving SE. Two-chamber septic tanks were installed on Sites 1, 2 and 3 while secondary treatment systems were installed on the other sites: an RBC (Biodisc®, Klargester) on Site 4 and peat filters (Puraflor®, Bord na Mona) on Sites 5 and 6. The site characteristics (see Table 1) show subsoils of different percolation T-values across the range 4 to 60 (equivalent to field saturated hydraulic conductivities in the range 0.07 to 1.05 m d⁻¹) as determined by the onsite standardised Irish falling head percolation test, the T-test.
(Mulqueen & Rodgers 2001; CEN 2006). The effluent from all four sites entered percolation trenches at 2.45 m centres built to EPA specifications (EPA 2000) consisting, in each case, of 110 mm diameter perforated PVC pipe bedded in 500 mm of gravel, 250 mm of which was below the pipe, in a 450 mm wide trench (see Figure 1) at a slope of 1:200.

**Instrumentation and sample analysis**

Automatic samplers (Bühler Montec) collected 24-h composite samples of STE and SE and ultrasonic flow monitors (Siemens Milltronics) or tipping bucket flow-gauges (Unidata, Australia) were installed downstream of the septic tanks and secondary treatment systems to obtain a profile of the effluent entering the percolation trenches. Suction lysimeters (Soilmoisture Equipment Corporation) were installed at the start (0 m), middle (10 m) and end (20 m) of each trench to nominal depths of 0.3, 0.6 and 1.0 m below the invert of the percolation trenches respectively (Figure 1a). More frequent lysimeters were installed in Sites 1 and 4 at distances 0, 5, 10 15 and 20 m of each trench to refine the analysis of biomat spread. At each site nine tensiometers (Soil Measurement Systems) were installed at the same three sampling depths along separate trenches in order to obtain a profile of soil moisture tension across the percolation area. Meteorological variables (rainfall, temperature, wind speed, relative humidity, solar radiation and sunshine hours) on each site were recorded by a weather station (Campbell Scientific) and rain gauges (Casella).

All STE, SE and soil moisture samples were analysed for ammonium, nitrite, nitrate, chemically oxygen demand, orthophosphate and chloride using a Merck Spectroquant Nova 6 spectrophotometer and associated reagent kits. The STE was also tested for total Kjeldahl nitrogen ascertain the fraction of organic and inorganic nitrogen present. Samples were analysed for indicator bacteria total coliforms and E. coli. Sites 2, 3, 5 and 6 were monitored for 12 months whilst Sites 1 and 4 were monitored for 18 months.

**RESULTS AND DISCUSSION**

**Method of analysis and effect of dilution**

Chloride was used initially as a crude tracer to identify areas across the percolation areas which were receiving wastewater effluent. The results of the laboratory analysis for Cl at the different sample positions along each trench were averaged at the same depth plane at which they were recorded. This enabled the identification of differences in loading rates between sampling distances on the same depth plane, thus highlighting any anomalies within each depth plane. From this a conceptual model (assuming isotropic and homogeneous soil properties) was derived for the

![Figure 1](https://iwaponline.com/wst/article-pdf/57/12/1921/438400/1921.pdf)
analysis of the attenuation of the percolating effluent according to one of the two following methods.

(i) **Planar average**: the averaging, across all trenches, of the concentrations of each parameter across all sampling positions at the 0.3, 0.6 or 1.0 m depth planes. The difference between the average loading rates was then compared for the different depth planes.

(ii) **Depth average**: the averaging, across all trenches, of each parameter within each plane was calculated at the different sample distances along the trenches and the corresponding differences in loading rates between the planes compared at these three distances.

An example of the planar average analysis method is shown in **Figure 2** for Site 2 where the similar chloride loading rates for all planes indicates that the effluent was spread across the whole length of the percolation area. Similar Cl analyses carried out on Sites 3, 4, 5 and 6 showed decreased concentrations at the 10 and 20 m sample positions along the same planes suggesting that depth average method was the more representative way to assess effluent attenuation on these sites, as highlighted by **Figure 3** which shows that the effluent was only being picked up at the 0 m sample position on Site 5. At Site 1 the results showed that the biomat had spread past the 0, 5 and 10 m sampling positions but not as far as the 15 m positions.

Loading rates at the different depths were then calculated on a daily basis according to a mass balance of effluent flow plus any rainfall recharge. The extent of effluent dilution in the subsoil from effective rainfall was calculated using rainfall figures and evapotranspiration figures obtained on site based on the Penman-Monteith method as described in Gill et al. (2007). Daily effective rainfall was calculated by subtracting the daily actual evapotranspiration and accumulated soil moisture deficit figures from the daily rainfall measurement. Examination of the soil moisture tension values from the tensiometers installed at the different sample positions on all sites were also used to confirm the conceptual models for each site. The tensiometers located at the positions where no effluent had been recorded reacted to the variation in effective rainfall over the sampling period, whereas the tensiometer readings at positions where effluent had been recorded were more constant. This also suggested that the rainfall dilution of the percolating effluent in the subsoil was relatively small.

**Chemical analysis**

The installation of the secondary treatment systems greatly reduced the organic load on the percolation areas as expected with an average 75% lower COD loads per capita being discharged to Sites 4, 5 and 6 compared to the sites with septic tanks. Correspondingly, the biomat lengths across the percolation areas receiving SE were muted compared to the sites receiving STE, as seen in **Table 1**. The effluent only reached up to a maximum of 5 m along the length of the SE percolation trenches with shorter biomat development for the higher permeability subsoil sites.

The average total-nitrogen loads of STE and SE discharged into the percolation trenches on each site over the research periods are shown in **Table 1**. When these were
compared to the respective loading rates after percolating through 1 m depth in the subsoil (taking into account the dilution by effective rainfall) significant differences were found between the sites receiving STE and SE in terms of the potential nitrogen loading to groundwater, particularly when comparing the sites of medium permeability (Sites 2 & 3 and Sites 5 & 6). The nitrogen in the STE, discharging mainly in the ammoniacal form (with approximately 20% organic-N), was seen to nitrify in the gravel and first 0.3 m of subsoil and then denitrify in the sporadically saturated conditions below the biomat. The secondary treatment systems on Sites 4, 5 and 6 clearly facilitated the nitrification of NH$_4$ in the effluent but while the SE underwent further slight nitrification within the subsoil, the nitrate remained largely unchanged as it percolated down through the subsoil, leaving higher total-N loads to the groundwater. The equivalent reduction in total-N load between the SE and point of discharge on Sites 4, 5 and 6 was only 22%, 9% and 26% respectively compared to 68%, 76% and 81% on the STE sites. Figure 4 compares this difference between the percolating STE on Site 2 to the SE on Site 5 where total-N loads of 16.7 g/d were found at the nominal point of discharge to groundwater on Site 5 compared to 6.8 gTotal-N/d at the same depth on Site 2. As NH$_4$ and NO$_3$ can be removed from the percolating effluent by immobilisation and/or denitrification, the inhibition to biomat formation along the percolation trench on the sites receiving SE would result in a reduction in microbial denitrification, (promoted in the biomat by the reducing conditions) thereby reducing the mass of inorganic-N released as gas. In addition, even if localised saturated conditions existed within the subsoils on Sites 4, 5 and 6, the organic load of the percolating effluent may not have been sufficient to support the facultative heterotrophs required for denitrification.

An interesting correlation can be seen in Table 1 between higher total-N loads per capita at 1 m depth and subsoil permeability for both STE and SE. This is particularly evident (see Figure 5) on the highly permeable subsoil Sites 1 and 3, where the SE again remained largely untouched in its nitrate form en route to the groundwater, as expected, but the STE on Site 1 did not appear to be denitrify as thoroughly as on Sites 2 and 3. The high permeability subsoil had muted the spread of the biomat even under a high organic loading promoting relatively high hydraulic loading on that localized area. The faster permeability of the subsoil beneath the biomat was then maintaining unsaturated aerobic conditions unsuitable for denitrification of the effluent.

It should also be noted that the peat modules on Sites 5 and 6 had to be adapted for the project by collecting all the percolated effluent to one outlet pipe to enable the effluent to be evenly distributed between the percolation trenches. This resulted in slightly flooded conditions in the base of the plastic modules, conditions which promoted 51% reduction in inorganic-N loading through the peat filter on Site 5 and 25% reduction on Site 6. Such anoxic conditions present in this shallow flooded zone are not typical for other types of secondary treatment systems and therefore it must be considered that the total-N load at the point of discharge to groundwater would normally be noticeably higher for SE, as demonstrated on Site 4.

The average results from the sites show that the potential total-N load to groundwater beneath the percolation areas from the secondary treatment systems was
approximately twice that compared to the sites receiving just septic tank effluent, or up to 3 times greater if the high permeability sites (which are rare in Ireland) are ignored. Finally, it should be emphasised that these research results have been derived from carefully installed and closely monitored on-site systems, where great care has been taken to ensure an even distribution of effluent across each percolation area. This does not appear to be the reality unfortunately for most existing on-site wastewater treatment systems in use today.

CONCLUSIONS

The results from the study of the three-dimensional performance of six percolation areas of different subsoil characteristics receiving on-site wastewater effluent indicate that the potential nitrogen loading to the groundwater from the percolation areas receiving secondary treated effluent was approximately two to three times that from the equivalent septic tank percolation areas. The reduced biomat formation on the percolation areas receiving SE resulted in more concentrated hydraulic loading of the effluent with a lower organic content which has muted denitrification. A correlation could also be seen between higher resultant nitrogen loadings and increased permeability of the subsoil for both secondary treated and septic tank effluent which resulted in relatively high nitrogen loads on the highly permeable sites. Finally, the study also showed that high nitrate concentrations, whether a direct health hazard or not, can act as an indicator of on-site pollution/contamination.

REFERENCES


