Nitrate leaching from construction sites to groundwater in the Nottingham, UK, urban area

F.T. Wakida* and D.N. Lerner**

* Groundwater Protection & Restoration Group, Department of Civil & Structural Engineering, University of Sheffield, Mappin Street, Sheffield S1 3JD and Facultad de Ciencias Químicas, UABC, Tijuana, Mexico
** Groundwater Protection & Restoration Group, Department of Civil & Structural Engineering, University of Sheffield, Mappin Street, Sheffield S1 3JD

Abstract Nitrate pollution has been identified as a major water quality issue in the UK. The aim of this project is to research the rate of nitrate leaching to groundwater that arises from construction works. The study area is situated in Nottingham UK, which is situated on the Triassic Sandstone aquifer. Soil samples up to a depth of 2.50 m were taken from three sites under construction and other land use. The results have shown a high variability in the concentrations of soil-nitrate. The reasons for this variability include soil type, past land use, soil treatment and type of vegetation prior to construction works. The average nitrogen load was 65 kg N ha⁻¹ which is higher than the nitrate leaching observed when temporary grassland is ploughed during autumn. The highest nitrate concentrations were observed in an allotment site (133 kg N ha⁻¹) due to the high amount of manure applied at this location. The construction practice of top soil stripping can produce a reduction of nitrate leaching because it removes the part of the soil that contains most of the potentially mineralizable nitrogen.

Keywords Construction sites; nitrate leaching; non-agricultural; Nottingham; Triassic Sandstone; urban groundwater

Introduction

Pollution of groundwater by nitrate (NO₃⁻) has been a frequent concern in aquifers throughout the world. It is often seen as an agricultural pollutant given that it arises from the use of fertilizer. A high difference in its concentration in aquifers beneath cities and agricultural land might be expected. However, recent studies in the UK have shown that this difference is small (Lerner et al., 1999). In addition to agricultural practices, there are non-agricultural sources that can contribute to the increase in nitrate concentrations in groundwater. Most of these sources are related to urban development.

House construction is as destructive of vegetation and soil organic matter as ploughing of pasture, which has been identified as a major source of nitrate from agricultural land. Hence nitrate leaching from housing development may be as great as that from ploughing. Whitmore et al. (1992) calculated that over 450 kg ha⁻¹ of nitrogen is lost from soil organic matter in the first season after ploughing. The authors suggested that the ploughing of pasture has contributed greatly to the increase in nitrate leached from farmland in England and Wales during the last 50 years. Cameron and Wild (1984) measured nitrate leaching following the ploughing of temporary grassland on chalk soils. At two sites the losses of nitrate due to winter leaching to depths below 90 cm were about 100 kg N ha⁻¹ over two winters, and at a third site were about 25 kg N ha⁻¹ over one winter. Some nitrogen leaching data from other studies of ploughed grassland are given in Table 1.

Ford and Tellam (1994) suggested house construction as one of the possible sources of the high nitrate concentration in the aquifer underlying the city of Birmingham. Lerner et al. (1999) used recharge and nitrogen concentration data to estimate the total N loading in the Nottingham urban area to be 21 kg ha⁻¹ year⁻¹. Contributions of the various N sources
are as follows: leaking mains, 37%; leaking sewers, 13%; soil leaching, 9% and other (contaminated land, industry, etc) 41%.

Young and Hall (1976), also in the United Kingdom, used data from deep bore studies to show that ploughing of grassland has been responsible for peaks in nitrate concentration seen in the unsaturated zone above aquifers.

Soil disturbance during construction

Soil is highly disturbed during construction due to common building practices. These encompass activities related to site preparation (soil stripping) and trenching for building foundations and the installation of underground services. Such activities can significantly alter the soil physical properties. House construction generally begins with the stripping and stockpiling of topsoil for later use on the site. The subsoil is then left exposed and can be compacted by construction traffic. At the end of construction, the topsoil is placed on top of and usually mixed with other construction materials. This process degrades the structures of the soil, decreasing the rate of infiltration (Hamilton and Waddington, 1999). Infiltration through the lawns of new houses can have high spatial variability due to variable compaction as a consequence of construction traffic. Hamilton and Waddington (1999) stated that infiltration rates through residential lawns increase with age due to an increase in macrofauna that results in macropores for preferential flow.

Topsoil disturbance increases soil aeration and mixes the available carbon and nitrogen sources with soil organisms. This process leads to nitrogen accumulation in the soil due to mineralization and nitrification. When the soil is left fallow during winter, nitrate is leached by drainage of excess water (McLenaghan et al., 1996).

Similar to nitrate leaching due to agricultural practices, leaching from construction sites can be influenced by a number of parameters such as soil characteristics, time and methods of construction, type of vegetation or land use prior to construction and rainfall. The type of vegetation prior to construction is very important. Different plants can accumulate or turn over different amounts of nitrogen, as indicated by the studies conducted in grassland or mixed grassland (grass and clover). More relevant to urban sites is the previous land use. Planning authorities in the United Kingdom encourage the redevelopment of urban “brownfield” sites rather than the use of “greenfield” sites (Department of the Environment, 2000). House building in Nottingham is therefore being conducted mainly on former industrial sites or former housing estates and is less common on open spaces and allotments (small pieces of usually public land rented by an individual for cultivation). The potential for nitrate leaching from housing developments may be high due to the disturbance of the former gardens during construction. These urban spaces are generally comprised of grassland more than five years old, which will have accumulated more nitrogen. On the other hand, if an allotment is used for construction it could lead to a higher nitrate leaching rate due to high use of manure and fertilizers by the tenants.

Study area

The study area is in the city of Nottingham, which is the second largest city in the UK Midlands.

### Table 1

Nitrate leaching rates of ploughed grassland from different studies

<table>
<thead>
<tr>
<th>Reference:</th>
<th>Nitrate leaching/yr kg N ha⁻¹</th>
<th>Vegetation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Francis et al. (1998)</td>
<td>36</td>
<td>Temporary pasture</td>
</tr>
<tr>
<td>McLenaghan et al. (1996)</td>
<td>33</td>
<td>Grass ley (not necessarily permanent grass)</td>
</tr>
<tr>
<td>Department of the Environment</td>
<td>93</td>
<td>Ploughed grass</td>
</tr>
<tr>
<td>Francis (1995)</td>
<td>72–142</td>
<td>Temporary leguminous pastures</td>
</tr>
</tbody>
</table>
Nottingham was chosen for the study since it is situated on an important aquifer and is the subject of past and present studies. Furthermore, the area has no significant drift cover to complicate the interpretation of results. The climate of the Nottingham area is temperate with an average annual precipitation and temperature of 711 mm and 9.4°C, respectively.

Soil in the area is sandy or loamy sand that passes into soft, reddish sandstone or unconsolidated sand between 80 and 120 cm below ground level. Nottingham overlies the Triassic Sherwood Sandstone aquifer, the second most important UK aquifer. The Sherwood Sandstone Group underlies approximately 40% of the city. Triassic Sandstones are underlain by Permian Marls and in the southern and western areas, are overlain by Triassic Mudstones, which act to confine the Sandstone aquifer in the east. In the valleys of the Rivers Leen and Trent, thin (1–5 m) alluvial deposits overlie the sedimentary sequence (Charsley et al., 1990). Groundwater flow in the area is from topographically high outcrops in the northwest towards discharge zones in the southeast. The hydraulic gradient is low due to the low relief of the land and the high permeability of the aquifer (Rivers et al., 1996).

Methods

Due to the difficulty in obtaining permission to sample, the sampling sites were selected on the basis of three main criteria: a) location on the sandstone outcrop b) sampling permission whether or not obtainable and c) past land use of the site.

Three sites under construction were sampled, using a hand auger, in 20 cm depth intervals to a maximum depth of 2.50 metres. Samples were taken to the laboratory and extracted within 24 hours. From the samples, 40 g subsamples were taken for 1:1 soil-water extractions. The suspension was centrifuged for 10 minutes at 8,000 rpm and filtered using a 0.45 µm nylon membrane. The solution was analyzed by Ion Chromatography. Additional subsamples were separated to measure soil water content and pH. Soil water content analysis was done gravimetrically by drying 15–30 g of soil for 24 hr at 104°C. pH measurements were made using a suspension (10 g air-dry < 2 mm soil and 25 ml of water) and shaking it for 15 min, before introducing an electrode to the suspension (Rowell, 1994). Three samplings were conducted at each site on different days in a period from December 1999 to November 2000. In every sampling at least four holes were dug. Construction works in most of the sites commenced in autumn (recharge season). All of these sites have an urban past land use (former house gardens or open spaces). Additionally, other urban spaces in the same area were sampled (allotments, urban open spaces with minimum soil disturbance). These sites were used as controls where appropriate. The sites are summarized in Table 2.

The nitrate-N loadings (kg N ha⁻¹) were calculated by multiplying the amount of NO₃⁻N (kg N kg⁻¹) in each vertical interval of the peak concentrations by the mass of soil in an interval of 20 cm (2,934 × 10⁶ kg ha⁻¹). The calculations were based on a soil bulk density of 1.467 g cm⁻³.

<table>
<thead>
<tr>
<th>Site</th>
<th>Previous land use</th>
<th>Construction site area (ha)</th>
<th>Soil description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hollies</td>
<td>Housing development</td>
<td>0.2</td>
<td>brown clayey sand</td>
</tr>
<tr>
<td>Kibworth</td>
<td>Allotment</td>
<td>0.3</td>
<td>loamy sand passing to sand with depth</td>
</tr>
<tr>
<td>Gleding</td>
<td>Housing development</td>
<td>0.3</td>
<td>loamy sand passing to sand with depth</td>
</tr>
<tr>
<td>Allotment</td>
<td>Allotment</td>
<td>n.a</td>
<td>brown sand</td>
</tr>
<tr>
<td>Lenton</td>
<td>Open space</td>
<td>n.a</td>
<td>light brown sand</td>
</tr>
<tr>
<td>Control site</td>
<td>Open space</td>
<td>n.a</td>
<td>light brown sand</td>
</tr>
</tbody>
</table>
**Results and discussion**

The profiles of nitrate-N for three sites are shown in Figure 1. These profiles are the geometric mean of four profiles sampled in each date. The first two profiles from The Hollies site in Figure 1a are very similar. They have a peak concentration around 70 cm depth. A downward movement of the peak concentration is observed by the third sampling date, although the peak concentration is lower. A different pattern is observed in the profiles for The Kibworth site (Figure 1b) in which the peak concentrations were higher at the later sampling dates. It showed a more dispersed peak concentration in the last sampling and a downward movement of 60 cm.

Results show a maximum concentration of 115 mg N l$^{-1}$ in porewater among the construction sites which occurred at a depth of 1.90 m in the first profile of the Gleding site. A high variability was observed between the values of the sites. This variability may be the result of different factors such as soil treatment and past land use. The importance of soil treatment is accentuated by the fact that all the construction sites sampled were previously housing developments. The coefficient of variation of soil-nitrogen has been reported at 10–20% for agricultural soils (Biggar, 1978). Therefore, it is expected that this variability may be higher in soil from construction sites due to the extensive soil disturbance associated with these sites.

In contrast, the downward movement of peak concentration cannot be seen clearly for the Gleding site profile (Figure 1c). In this profile the peak concentration for the first sam-

![Figure 1 Profiles of soil nitrate concentration from different construction sites: (a) Hollies and control site; (b) Kibworth and (c) Gleding. Every profile is the geometric mean of four samples taken on each date](https://iwaponline.com/wst/article-pdf/45/9/243/425724/243.pdf)
pling is deeper than the later two sampling dates. Secondary peak concentrations were observed at 50 cm depth in the first two samplings and a peak concentration in the third sampling was observed at 160 cm. This may be the result of the downward movement of the peak concentrations. An additional profile of the control site was added to the first profile (Figure 1a) for comparison. The control site is an urban lawn on which the soil has been undisturbed for at least 30 years and the soil has similar physical characteristics to the sampling sites. The profile indicates that nitrate leaching at this site is almost negligible. Therefore, the nitrate-N found in construction sites is the result of soil disturbance.

Nitrate loads calculated for the sampling sites are shown in Table 3. The mean nitrogen load was 65 kg N ha⁻¹ for the three sites. This value is higher than the nitrate leaching (50 kg N ha⁻¹) observed when temporary grassland is ploughed (Cameron and Wild, 1984), but lower than the calculated potential nitrate leaching (450 kg N ha⁻¹) from ploughing permanent grassland (Whitmore et al., 1992). The maximum nitrogen load amongst the construction sites was at the Kibworth site, which was a semi-derelict allotment. However, it was not significantly higher than the load calculated for the Gleding site which was constructed on a former housing development. The highest nitrate load was observed in the ‘active’ allotment site. This is because of the high amount of manure typically applied at these sites. However, this does not represent a significant source of nitrate in urban areas due to the small land areas involved. It is important to note that all the peak concentrations exceeded the drinking water standard (11.3 mg N l⁻¹).

Conclusions
Estimates were made of the amounts and concentrations of nitrate released during house-building in the urban area of Nottingham. The following was concluded:
1. The average nitrate leaching from the three sites under construction was estimated at 65 kg N ha⁻¹.
2. The high soil disturbance during construction leads to a high variability of nitrate concentration. A maximum value of 116 mg N l⁻¹ was observed. Moreover, the use of heavy machinery on construction sites after topsoil stripping leads to a high variability of soil parameters such as infiltration and soil density. These parameters also influence potential nitrate leaching.

Acknowledgements
This work is part of a research project funded by the National Environment Research Council (NERC) (GR9/04319). The authors acknowledge the financial support provided by the National Council of Sciences and Technology of Mexico (CONACYT) for the PhD scholarship to F.T. Wakida. The authors also thank Ms Ishrat Baig for help in field sampling.

Table 3 Maximum peak concentrations and load of NO₃-N observed in the construction sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Maximum/minimum NO₃-N peak concentration observed in the different date profiles (mg N l⁻¹)</th>
<th>Geometric mean of NO₃-N load (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hollies</td>
<td>57/39</td>
<td>53</td>
</tr>
<tr>
<td>Kibworth</td>
<td>93/48</td>
<td>76</td>
</tr>
<tr>
<td>Gleding</td>
<td>116/40</td>
<td>66</td>
</tr>
<tr>
<td>Allotment*</td>
<td>88</td>
<td>133</td>
</tr>
<tr>
<td>Lenton</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Control site</td>
<td>4</td>
<td>= 0</td>
</tr>
</tbody>
</table>

* The Nitrate-N loading was calculated adding all the nitrate-N deeper than 90 cm
References


