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# Non-agricultural sources of groundwater nitrate: a review and case study

Fernando T. Wakida[a,*], David N. Lerner[b]

[a]*Facultad de Ciencias Químicas e Ingeniería, Universidad Autónoma de Baja California, Calzada Universidad, Mesa de Otay, Tijuana, Baja California, México*

[b]*Groundwater Protection and Restoration Group, Civil & Structural Engineering, University of Sheffield, Mappin St, Sheffield, S1 3JD, UK*

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**Abstract**

Nitrate is often seen as an agricultural pollutant of groundwater and so is expected to be at higher concentrations in the groundwaters surrounding a city than in those beneath it. However the difference between rural and urban nitrate concentrations is often small, due to the non-agricultural sources of nitrogen that are concentrated in cities. This paper illustrates the source and significance of non-agricultural nitrogen for groundwater and presents a case study of nitrate loading in the city of Nottingham. Major sources of nitrogen in urban aquifers are related to wastewater disposal (on-site systems and leaky sewers), solid waste disposal (landfills and waste tips). The major sources of nitrogen in the Nottingham area are mains leakage and contaminated land with approximately 38% each of a total load of 21 kg N $ha^{-1}$ $year^{-1}$.
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## 1. Introduction

Nitrate is a compound of nitrogen that occurs naturally in moderate concentrations in many environments. Baseline concentrations of nitrate in groundwater beneath natural grassland in temperate regions are typically below 2 mg $l^{-1}$ (Foster et al., 1982). Because it is very soluble, it is the most usable form of nitrogen for plants. Nitrate is a common surface water and groundwater contaminant that can cause health problems in infants and animals, as well as the eutrophication of water bodies (Fennesy and Cronk, 1997).

Nitrate has been linked to agricultural activities due to the use of fertilizers. However, there are other nitrate sources related to urban development that can increase nitrate concentrations in groundwater. Studies in the last few years have found that nitrate concentrations in some urban aquifers are similar or even higher to those in their surrounding agricultural areas (Ford and Tellam, 1994; Lerner et al., 1999). The objective of this paper is to illustrate the sources and significance of non-agricultural sources of nitrate in groundwater.

## 2. Non-agricultural sources of nitrogen in groundwater

The wide range of pollutant sources and the complexity of recharge in urban areas make the estimation of

*Corresponding author. PMB # 184, 710 East San Ysidro Blvd "A", San Ysidro, CA 92173, USA. Tel.: +52 664 6821033; fax: +52 664 6822790.

*E-mail addresses:* fwakida@uabc.mx (F.T. Wakida), d.n.lerner@sheffield.ac.uk (D.N. Lerner).

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pollutant load a difficult task in these areas. This is also true for the various forms of nitrogen (oxidized and reduced forms) that are present in many possible recharge sources of urban aquifers. They include sewage and mains leakage, septic tanks, industrial spillages, contaminated land, landfills, river or channel infiltration, fertilizers used in gardens, house building, storm water and direct recharge. Because of the number of nitrogen sources in urban areas, it is not surprising to find elevated nitrogen concentrations in urban aquifers. The sources of nitrogen in the urban environment are a mixture of point sources (e.g. landfills and coal gasification works), multipoint sources (e.g. soakaways and leaky sewers) and diffuse sources (atmospheric deposition, house building and recreation areas). An overview of these sources is presented in the following sections and Table 1 reviews some published cases.

### 2.1. Leakage from water supply and disposal networks

Leakage from sewerage and water supply networks provides the highest percentage of water recharge to aquifers underlying many cities through out the world (Yang et al., 1999; Lerner, 1986). Water mains and sewers leak because of improper installation or deterioration through age, subsidence or earthquakes. Sewage leakage occurs when sewers are situated above the water table. Few studies have attempted to quantify the recharge and pollutant load from leaky sewers. Published examples of leaky sewers studies are mainly from Germany. In Hanover, 5–8 $Mm^3\,year^{-1}$ of sewage is entering to the aquifer (Mull et al., 1992). It is estimated that more than 100 $Mm^3\,year^{-1}$ of wastewater percolates from damaged sewers to subsurface in Germany (Eiswirth et al., 2000). On the other hand, mains leakage is almost an inevitable fact for water supply companies and losses of 20% are considered routine in the United Kingdom (UK). For Liverpool, it was calculated a leakage of 36.5 $Mm^3\,year^{-1}$ equivalent to a recharge of 180 $mm\,year^{-1}$ (Price and Reed, 1989) and in the city of Amman, Jordan the leakage from water-supply system is approximately 24 $Mm^3\,year^{-1}$ (Salameh et al., 2003). This review has shown leaky sewers and mains have a major impact on groundwater quality. Leaky sewers contribute with a wide range of pollutants such as bacteria or organic and inorganic compounds. On the other hand, water supply is often of good quality. Nitrogen concentrations are likely to be under the drinking water limit of 10 $mg\,l^{-1}$ and so leakage can be beneficial for pollutant dilution.

### 2.2. On-site sewage disposal

On-site sewage disposal encompasses cesspools, septic tanks and pit latrines. It is estimated that in the United States approximately one third of its sewage is disposed of by septic tanks (Harman et al., 1996). Septic tanks are also a common practice in other countries such as Canada and Australia, as well as in developing countries (Harman et al., 1996; Whelan, 1988). In Sana'a, Yemen, it is estimated that 80% of the urban recharge is wastewater from cesspits (12.5 $Mm^3$ in 1993) (Alderwish and Dottridge, 1999) and in the city of Amman, Jordan, 8 $Mm^3\,year^{-1}$ from cesspool leakages are recharging the aquifer (Salameh et al., 2003). Conversely, in the UK only 5% of the population is not served by mains sewerage and most of these are served by septic tank systems (Payne and Butler, 1993).

The concentration of total nitrogen in effluents from a typical septic tank system ranges from 25 to 60 $mg\,l^{-1}$, with ammonia making up the vast majority of this total, 20–55 $mg\,l^{-1}$ as ammonia and less than 1 $mg\,l^{-1}$ as nitrate (Canter, 1997). Ammonium ions in the effluents may be oxidized to nitrate which can be transported in the subsoil beneath the septic tank absorption field and subsequently to groundwater.

The density of systems is the most important factor in groundwater contamination by septic tanks. A minimum lot size of 0.4 to 0.6 ha is needed to insure against groundwater contamination (Bicki and Brown, 1991). Other factors that can contribute to the hazard of groundwater pollution by septic tanks are improper design, poor maintenance and depth of the water table (Yates, 1985).

A greater threat to groundwater quality is the use of pit latrines because of the discharge of waste without pre-treatment. Human excreta contains about 5 $kg\,N\,year^{-1}$ per capita (Lewis et al., 1980). Therefore, high population density plays an important role in the impact of this waste disposal method.

### 2.3. Animal waste

Animals are, or have been a common feature in many cities in the world. Cats, dogs and less commonly horses and urban wild animals are inhabitants in many cities. In the suburbs of cities in developing countries, it is common for people to keep some farm animals for consumption or for commercialization. For example, there are about 23,000 dairy cows in the urban and peri-urban areas of Addis-Abeba, Ethiopia (Bonnet and Duteurtre, 1999) and approximately 60,000 cows in the metropolitan zone of Mexico City (Lozada et al., 2000). Somasudaran et al. (1993) suggested the substantial number of oxen, cows and buffaloes in Madras, India, is one of the sources of the high nitrate concentration in shallow groundwater. Excreta, dung and urine produced by animals constitute a potential source of contaminants such as nitrate, potassium and bacteria. They can enter groundwater by way of storm water channels or river, recharge basin or direct recharge.

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