The impact of horse dung on urban groundwater quality in the Birmingham Triassic sandstone aquifer, UK

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Abstract The aim of this study was to evaluate the role of pollution from horse dung (and urine) on groundwater quality in the UK Birmingham Triassic sandstone, an example urban aquifer. Urban horse populations were estimated for the period 1750 to 1970, interpolating where necessary using human and horse population statistics for other parts of the UK. Horse numbers increased from around 1000 in 1750 to a peak of around 12 000 in 1910, thereafter falling to <1000 by 1970. The waste produced would have been 100-200 x 10^3 t per year in 1910. Using data on dung (and urine) composition from the literature, and dung composition from leaching tests, chemical fluxes in recharge were estimated. It was concluded that on a regional scale the impact of horse wastes would have been a significant but not dominant input to some chemical balances. However, locally, considerable pollution would have occurred.

Key words dung; pollution; sandstone; Triassic; urban aquifers

INTRODUCTION

In many cities in the world there are, or have been, large animal populations, and the dung and urine produced by these animals constitutes a potential source of pollution which has rarely been estimated. This paper presents the results of a study to evaluate the groundwater pollution arising from horse wastes in the Triassic sandstone aquifer underlying Birmingham, UK. Only inorganic pollutants have been considered.

THE BIRMINGHAM AQUIFER

Birmingham is underlain by Quaternary deposits resting on Triassic sandstone which varies from zero to several 100 m in thickness and is a fine- to medium-grained red-bed sequence. It has been used for industrial and, up to the early 1900s, public water supply. Groundwater quality varies considerably with local land use (Ford & Tellam, 1994). NO₃ and Cl concentrations are relatively high. However, the only inorganic species for which the median concentrations approach European Union health limits are NO₃ and Ba.

HORSE POPULATIONS IN BIRMINGHAM

Horses have been much used in the past in Birmingham (Holden, 1989; Jenson, 1978; Turner, 1998). There are only sparse data on historical horse populations in Birmingham, and hence estimates have been made using data on human populations
and horse populations for the UK and for London. The definition of “Birmingham” is the area of the current conurbation (~110 km²).

Horse populations from 1810 to 1940, were estimated using:

$$H_B = \frac{P_B H_{UK}}{P_{UK}} \left( \frac{H_B / P_B}{H_{UK} / P_{UK}} \right)$$

1920 or 1924 or 1934

where $H =$ horse population, $P =$ human population, subscript $B =$ Birmingham, and subscript $UK =$ UK. The term in brackets can be evaluated for the three dates for which data on horse populations exist (1920, 1924 and 1934 (Chives, 1976)); these three values result in different estimates of $H_B$, and the maximum and minimum values are both presented in the figures below. Human and UK horse population statistics were obtained from Mitchell (1985) and Thompson (1983) respectively. In the time interval 1810–1940, the horse/human population ratio in Birmingham was apparently around 20% of that in the country as a whole.

No horse population data exist for prior to 1810, but values exist for London for 1752 and 1765. Hence for these two dates a similar approach was adopted. The horse/human population ratios for Birmingham were 76% of those for London in 1920, and 101% in 1934.

After 1940 the only data available are for horses kept on farms (livestock) (Mitchell, 1988). Accordingly the total horse/livestock ratios for the UK were estimated for 1810 to 1940 (data from Thompson (1983) and Mitchell (1988)), and the 1940 ratio was then multiplied by the yearly horse livestock populations to obtain estimates of horse populations after 1940. The horse livestock populations were also calculated for prior to 1810, so that an estimate of farm horses in the Birmingham area could be obtained as a function of time from 1752 to 1970.

Figure 1 shows the estimated populations of horses. The population appears to have increased from around 1000 in the late 1700s to a maximum of 11 000–14 000 around 1910, and thereafter rapidly declined to less than 1000 in 1970. It is probable that the number of horses in Birmingham in the later part of the 1800s has been underestimated, because by the time for which the best data are available the petrol engine was in heavy use. It is expected that the data for the period after 1920 are more accurate though possibly slightly overestimated.

**Fig. 1** Maximum and minimum estimates of horse populations in Birmingham.

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**THE RATE OF PRODUCTION OF DUNG AND URINE BY HORSES**

The production of dung will depend on animal weight, amount of feed and water, activity, and housing system. In general, a horse within the weight range 500–600 kg,
fed daily 8–10 kg of grass, oats, and straw, will excrete 21.5 to 38.5 kg of solid waste per day, 28.5 kg on average (Bienz & Menzi, 1999). Using these data, Fig. 2 shows the dung production as a function of time in Birmingham.

Brown (1984) reports that a horse excretes about 10 l of urine a day. This would amount to a flux of ~0.1 mm year⁻¹ in 1910 at around the time of the greatest horse populations (Fig. 2). This compares with an average recharge of around 150 mm year⁻¹.

![Fig. 2 Maximum and minimum horse dung and urine production estimates for Birmingham.](image)

**CHEMICAL COMPOSITION OF HORSE DUNG AND URINE**

Horse dung is typically enriched in organic matter, N, P, K, metals, and microorganisms. Table 1 lists some summary compositions produced by Bienz & Menzi (1999), Edwards et al. (1999), and Taigainides & Stroshine (1971).

<table>
<thead>
<tr>
<th>(a)</th>
<th>Total solids</th>
<th>Organic matter</th>
<th>Ash</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>343</td>
<td>304</td>
<td>38.9</td>
<td>3.9</td>
<td>1.75</td>
<td>6.0</td>
<td>0.67</td>
</tr>
<tr>
<td>Not fresh</td>
<td>352</td>
<td>255</td>
<td>97.6</td>
<td>5.9</td>
<td>3.32</td>
<td>11.1</td>
<td>1.4</td>
</tr>
<tr>
<td>(b)</td>
<td>Horse mass</td>
<td>N</td>
<td>P₂O₅</td>
<td>K₂O</td>
<td>Mg</td>
<td>Ca</td>
<td></td>
</tr>
<tr>
<td>Working/ riding</td>
<td>500 (kg)</td>
<td>60</td>
<td>28</td>
<td>110</td>
<td>8</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Mares</td>
<td>500 (kg)</td>
<td>85</td>
<td>39</td>
<td>150</td>
<td>11</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>Al</td>
<td>As</td>
<td>B</td>
<td>Cd</td>
<td>Co</td>
<td>Fe</td>
<td>Mn</td>
</tr>
<tr>
<td>396</td>
<td>17.7</td>
<td>10.7</td>
<td>1.7</td>
<td>2.8</td>
<td>392</td>
<td>120</td>
<td>1.8</td>
</tr>
<tr>
<td>(d)</td>
<td>P</td>
<td>K</td>
<td>Ca</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% excreted in urine</td>
<td>0</td>
<td>58</td>
<td>45</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% excreted in dung</td>
<td>100</td>
<td>42</td>
<td>55</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mg l⁻¹ (approx.)</td>
<td>0</td>
<td>2000</td>
<td>7000</td>
<td>8000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MAXIMUM POTENTIAL POLLUTION FLUX**

Using the data on horse numbers and waste production rates and composition, the maximum potential pollution production as a function of time can be calculated. The
results are shown in Fig. 3. Although production of waste is substantial, the waste was probably concentrated in particular regions (stables, heavily used roads), and some would have been collected for fertilizer use. In addition, not all of the inorganic components of the dung would be leachable.

Fig. 3 Chemical loading from horse dung as a function of time in Birmingham.

LEACHING TESTS

To provide an indication of the amount of soluble material that can be leached from dung by recharge water, scoping laboratory experiments were undertaken.

One gramme samples of fresh dung were placed in 12 bottles and 100 ml of de-ionized water (pH 5.8) was added to represent rainwater. The bottles were placed on a mechanical shaker and shaken for various intervals from 5 min to 30 days. On removal from the shaker the bottles were left to stand for 20 min and the supernatant filtered through a 0.45 μm filter. Samples were stored in the dark at ~4°C until analysed for Si, K, Mg, Ca, Na, Al, Sr, Fe, Mn, Ba, Ca, Zn, Cr, Ni, and Cd by ICP-AES, and Cl, N species and P by automated colorimetry. The experiment was repeated on the same sample of dung starting on various dates: 20 March, 28 March, 5 April and 24 May 2000. Some tests were also repeated using 2 g samples.

Example results are shown in Fig. 4. Clearly the simple leaching tests performed here should not be interpreted in detail as the results are likely to be sensitive to the procedure used and will not precisely represent conditions in the field. However, they provide a first-pass indication of leachable content. No NO₃, Cd, Pb, or Ni was detectable (detection limits 0.5, 0.02, 0.2, and 0.08 mg l⁻¹ respectively). Zn, Cl, P, K, Mg, Na, Ca and Mn vary little with time after attaining a steady concentration within a day or two. Al, Si and Fe concentrations rise to a peak and then fall to a steady value after around 10 days. NH₄ concentrations rise to a peak at around 10–15 days, and slowly decline thereafter. There is no strong relationship between results and the age of the dung, though possibly Si concentrations increase and Ca decrease with age. pH showed an asymptotic decrease from ~8.5 to just over 6 over the 30 day period, with all experiments showing very similar results. In general, doubling the mass of dung doubled the concentrations observed. Overall it appears that most of the P, Mn and Na in the dung was probably leached, significant proportions (35–67%) of K, Mg, Al, Fe, and Zn were leached, and little of the total N, Cd and Pb was leached.
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ESTIMATION OF MAXIMUM RECHARGE WATER POLLUTANT FLUX FROM HORSE WASTE

The results from the leaching tests were used to estimate initial concentrations in recharge waters arising from leaching of dung. Assuming the dung is uniformly distributed across the city and that the leaching tests are a reasonable indication of rainfall/dung interactions, concentration in recharge (C) is given by:

\[ C = \frac{C_{LT} V_{LT} M_B}{M_{LT} R_B} \]

where \( C_{LT} \) is the final concentration in the leaching tests, \( V_{LT} \) is the volume used in the leaching tests, \( M_B \) is mass of dung produced per year in Birmingham, \( M_{LT} \) is the mass of dung used in the leaching tests, and \( R_B \) is recharge (\( \sim 1.45 \times 10^{-10} \) year\(^{-1} \)). Selected results are shown in Fig. 5. The concentrations are not excessive. Comparison with median groundwater concentrations (Ford & Tellam, 1994) indicates that the concentrations in the dung-affected recharge, when at their maximum values in around 1910, are equivalent to 25\% of the N concentration in the groundwater, 12\% of Mg, 5\% of Ca, 33\% of Na, and 17\% of Cl. Fe, Zn, Mn, Cu, K, and PO\(_4\) concentrations are around 80, 28, 455, 8, 5.5, and 400 times the median groundwater values respectively. As: (a) these values are maxima, (b) no soil/rock reactions have been considered, and (c) the water in the pumped boreholes is diluted by deep unpolluted groundwater, the likely contribution from the dung is limited. However, the dung was probably concentrated in certain locations in the city. Consider a dung heap of porosity 70\% and density 1200 kg m\(^{-3}\). The water/dung ratio will be around 2.3 compared with the ratio used in the leaching experiments of 125; this means that, all else being equal, locally the concentration in the recharge water will be over 50 times greater. It is interesting to note that the condensate in the dung storage container contained >200 mg l\(^{-1}\) NH\(_4\). Clearly many assumptions have been made but it is probable that local pollution will have been severe, and this water will still be in the aquifer.

Although urine production is a small proportion of total recharge, concentrations of salts in urine are high (Table 1(d)). On average, ignoring any other processes (runoff, evaporation, reaction) urine fluxes would be likely to change recharge concentrations by around 10 mg l\(^{-1}\) for K and 5 mg l\(^{-1}\) for Ca and N. The conclusions for urine are therefore similar to those for dung.
Fig. 5 The estimated effect of dung leaching on recharge water quality using data from leaching tests.

CONCLUSION

On a regional scale, wastes from horses in Birmingham and similar cities are unlikely to have been a dominant contributor to observed groundwater pollution. However, horse waste is a significant contributor of pollution, and local severe pollution close to stables (and other animal quarters) appears probable. This study has not considered microbiological pollution. As viable human viruses are known to be present in deep groundwater in both Birmingham and Nottingham (Powell et al., 2000), and even extremely low concentrations are significant, further work would be of interest.

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REFERENCES