PREDICTION OF GROUNDWATER NITRATE CONCENTRATIONS
(CS 9248)

Progress report to Department of the Environment
1 January to 30 June 1989

DoE 2210-M

JUNE 1989
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CONTRACT REPORT

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OBJECTIVES

1) To apply the predictive model developed by WRc to selected catchments in which groundwater nitrate concentrations are rising and likely to exceed the EC MAC unless remedial action is taken; to assess the efficacy of various remedial measures.

2) To further refine the predictive model to make it more readily applicable to groundwater catchments, to take account of newer crops and land management practices, to simulate organic as well as organic fertiliser usage and to simulate denitrification which may be active in confined aquifers.

3) To assess the current situation with regard to nitrate in private well supplies and predict future trends.

REASONS

Nitrate concentration in many groundwater sources are causing concern to water undertakings. Reliable methods of predicting future trends are required to facilitate policy decisions and investment plans.

It is suspected that the nitrate concentrations in private wells are generally greater than in comparably situated public supply wells. A survey of nitrate concentrations in private wells is needed to indicate the scale of the problem, and to assess likely future trends.

RESUME OF CONTENTS

Modifications to the model to accommodate changes in cereal husbandry since the late 1970’s are presented. The revised model was able to accurately simulate the observed nitrate trends in both rapid response and slow response aquifers. It was predicted that the recent decline in groundwater nitrate concentrations in the Cambridgeshire Chalk will
soon be replaced by the rising trend, and that concentrations will be approaching 50 mg NO₃/l by the year 2040.
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SECTION 1 - INTRODUCTION

As described in the last progress report, the method of calculating the leaching loss from winter cereals in the WRC model was altered in the light of trends in the Lincolnshire limestone. Nitrate concentrations in this rapid response aquifer have generally declined since about 1980. The model was able to reproduce the observed trends after modifications to the leaching calculation based on the published work of Whitmore and Addiscott\(^{(1)}\). A significant change in nitrate trends has also been observed in the Cambridge Water Company chalk sources. Some appear to have stabilised since about 1980, whilst others have exhibited an overall decline. This represents a significant deviation from the WRC predictions undertaken as part of the Laurence Gould study in 1985. The chalk of Cambridgeshire comprises a slow response aquifer and there was some doubt as to the ability of the WRC model to correctly predict the observed trends using the revised leaching calculation. The model has therefore been rerun with up to date agricultural data and using the amended rates of leaching from winter cereals.

SECTION 2 - NITRATE LEACHING CALCULATION

Nitrate trends in the Lincolnshire limestone indicated that there had been a significant reduction in leaching losses from about 1980. It was thought that the reduction was due to:

i) earlier planting of winter cereals (mid to late September rather than mid to late October),

and

ii) reduction in autumn applications of nitrate fertiliser to cereals, following ADAS advice.

Both activities have become widespread since the early 1980’s. The size of reduction in nitrate leaching was estimated from calculations
by Whitmore and Addiscott\(^1\) who showed that the combined effect of these two activities would be to reduce nitrate leaching by 40 kg N/ha on average. In the light of this information the leaching calculation method was revised, and is now as summarised in Table 1.

**Table 1 – Model leaching rules**

<table>
<thead>
<tr>
<th>LAND USE</th>
<th>EQUIVALENT N LEACHED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter cereals</td>
<td>40% N applied *</td>
</tr>
<tr>
<td>Peas</td>
<td>50 kg N/ha/a</td>
</tr>
<tr>
<td>Other arable</td>
<td>50% N applied</td>
</tr>
<tr>
<td>Cut grass</td>
<td>10% N applied</td>
</tr>
<tr>
<td>Grazed grass</td>
<td>15% N applied</td>
</tr>
<tr>
<td>Ploughed grass</td>
<td>280 kg N/ha</td>
</tr>
<tr>
<td>Woodland/urban</td>
<td>2-3 mg N/l</td>
</tr>
</tbody>
</table>

* Reduced by 40 kg N/ha/a for soya post 1984 with smaller reductions back to 1978

This adjustment resulted in predictions that were in excellent agreement with measured concentrations of nitrate in water extracted from the Lincolnshire limestone, Figure 1.

**SECTION 3 – CAMBRIDGESHIRE CHALK MODEL**

### 3.1 HYDROLOGY AND HYDROGEOLOGY

The area modelled in the Laurence Gould study, and used also for the present study, is shown in Figure 2. The model area extends to the edge of the Chalk outcrop in the north west, and to the groundwater divide in the south east which is located in the boulder clay covered chalk. The principal direction of groundwater flow is approximately north west towards the public supply wells and rivers. There is evidence from groundwater levels of some recharge through the boulder clay, and following the work of Wright\(^2\) this has been assumed to
equal 30\% of the recharge to the outcrop chalk. The recharge rate to the chalk has been reassessed using data from lysimeters installed near to the Fleam Dyke pumping station. A 5 m deep lysimeter was constructed at Fleam Dyke in 1977, and measurements of drainage from the lysimeter have been used to calculate the rate of recharge to the chalk\(^3\). The data have been compared with Meteorological Office estimates of effective recharge calculated under the MORECS system. The Fleam Dyke lysimeter is grass covered, and so the comparison has been with MORECS values for grass. Unfortunately, the comparison has only been possible for a relatively brief period, 1978 to 1980 inclusive, but it would seem that MORECS is overestimating evaporation by about 45 mm/a. This may be due in part to the fact that there is no data source for the MORECS calculation within the 40 km grid square which covers the area. The apparent error in MORECS has been assumed to apply to the entire catchment, so that the average recharge rate to the outcrop chalk was estimated to be 185 mm/a. This compares with a value of 140 mm/a used in the previous study. The value of 185 mm/a is in very close agreement with estimates by the Cambridge Water Company based on borehole catchment areas. On the boulder clay, the total effective rainfall was assumed to be 185 mm/a also, with 30% percolating down to the underlying chalk, and the residual 70% running off the clay onto the chalk where it augmented direct recharge. A groundwater flow model was constructed and was able to reproduce the general groundwater trends in the catchment, Figure 3. The water balance for the area was:

Rainfall recharge       60 M m\(^3\)/a  
Groundwater abstractions  16 M m\(^3\)/a  
Baseflow to rivers       44 M m\(^3\)/a  

3.2 NITRATE LEACHING

Nitrate leaching was calculated for the period 1945 to 1986 using data from the parish statistics and from the FMA fertiliser use surveys. For the period up to 1980 the data were the same as used in the Laurence Gould study. Recent data were used to provide data up to 1986. Current land use may be summarised:
<table>
<thead>
<tr>
<th>Crop</th>
<th>% of area</th>
<th>N kg/ha/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter cereals</td>
<td>51</td>
<td>160</td>
</tr>
<tr>
<td>Spring cereals</td>
<td>9</td>
<td>110</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>6</td>
<td>135</td>
</tr>
<tr>
<td>Oil seed rape</td>
<td>4</td>
<td>260</td>
</tr>
<tr>
<td>Other arable</td>
<td>9</td>
<td>35</td>
</tr>
<tr>
<td>Grass</td>
<td>9</td>
<td>50</td>
</tr>
<tr>
<td>Non agricultural</td>
<td>12</td>
<td>-</td>
</tr>
</tbody>
</table>

Using the leaching rules of Table 1, catchment averaged leaching rates were calculated, Figure 4. The leaching rates were identical to those calculated in the Laurence Gould study up to the year 1978, but thereafter they diverged significantly. This is a result of the lower leaching loss from winter cereals consequent on earlier planting and reduced autumn nitrogen applications. It was assumed for all predictions of future trends that leaching would continue at the 1986 rate.

### 3.3 NITRATE IN GROUNDWATER SIMULATIONS

Nitrate leaching losses were applied to the groundwater flows to calculate groundwater nitrate concentrations. The earlier model had assumed that 15% of the rainfall recharge moved rapidly down to the water table via cracks and fissures in the unsaturated chalk. This value had been calculated from tritium profiles in the Cambridgeshire Chalk. With the increase in average recharge from 140 mm/a to 185 mm/a this calculation now required 30% of the recharge to move quickly down to the water table, by-passing the chalk matrix. In the revised model, therefore, a rapid recharge proportion of 30% was assumed.

The nitrate model was run from 1945, and gave accurate simulations of nitrate trends in the public supply wells with the exception of Linton where the model consistently under-predicted. This feature was thought to be due to an inadequate representation in the model of the nearby River Granta. This river has a relatively high nitrate concentration, but in the model was represented as nitrate free because of lack of data. At all the other boreholes the model simulations agreed well with observations, giving a rising trend up to about 1980 followed by a
levelling off, or in some cases a decline, in nitrate concentrations, Figures 5-10.

Lack of long term data on recharge from the Fleam Dyke lysimeter precluded the use of real recharge data in the nitrate model, and the simulations were undertaken with a repeating yearly value of 185 mm. For this reason there is little variability from year to year in the predicted concentrations. Some simulations were undertaken with a synthetic recharge sequence based on yearly data from the Lincolnshire limestone but with a long term average of 185 mm/a. These simulations produced a significant variability from year to year, Figure 11, which is similar to the variability in measured concentrations.

3.4 PREDICTION OF FUTURE TRENDS

It was predicted that the levelling off, or decline, in nitrate concentrations will soon be replaced by a rising trend, Figure 12. This results from a continuing leaching loss of 30 kg N/ha/a (equivalent to 70 mg NO₃⁻/l in the recharge water), and interaction between water in the fissures and in the chalk matrix below the water table. The predicted average nitrate concentrations in 2040 were:

<table>
<thead>
<tr>
<th>Location</th>
<th>Concentration (mg NO₃⁻/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westley</td>
<td>44</td>
</tr>
<tr>
<td>Pulbourn</td>
<td>51</td>
</tr>
<tr>
<td>Great Wilbraham</td>
<td>48</td>
</tr>
<tr>
<td>Fleam Dyke</td>
<td>49</td>
</tr>
<tr>
<td>Babraham</td>
<td>48</td>
</tr>
<tr>
<td>Sawston</td>
<td>41</td>
</tr>
<tr>
<td>Linton</td>
<td>39</td>
</tr>
</tbody>
</table>

NB At Linton the historic simulation was about 4 mg NO₃⁻/l too low.

The predictions are significantly different to those obtained during the Laurence Gould study; it was then predicted that concentrations would exceed 50 mg NO₃⁻/l in general by the year 2000.
SECTION 4 - CONCLUSIONS

1. A reduction in leaching losses from winter cereals in recent years has been identified as the cause of a nitrate decline in the rapid response Lincolnshire limestone. A reduction of 40 kg N/ha allowed the nitrate prediction model to accurately simulate the observed trends.

2. In the much slower response chalk aquifer of Cambridgeshire, similar trends have been observed. Using the revised leaching rule for winter cereals, the model was able to simulate the observed nitrate trends in the public supply wells.

3. Predicted nitrate concentrations over the next 50 years are significantly lower than in the earlier version of the model used in the Laurence Gould study. However, it was predicted that concentrations will begin to rise again soon and will be approaching 50 mg NO$_3$/l by 2040.

4. As part of the study the rainfall recharge to the chalk was recalculated to be about 30% larger than the MORECS value previously used. The increase in recharge was an important component in the revised nitrate simulation. In the light of the substantial changes in predicted nitrate concentrations re-evaluation of other groundwater catchments should be made using up to date land use and recharge data.
REFERENCES


Figure 2  CAMBRIDGESHIRE CHALK CATCHMENT AREA
Figure 3  SIMULATED GROUNDWATER LEVELS (m)
Figure 5  OBSERVED AND SIMULATED NITRATE CONCENTRATIONS

WESTLEY

mgNO_3/1

Figure 5  OBSERVED AND SIMULATED NITRATE CONCENTRATIONS

GT WILBRAHAM

mgNO₃/l

Figure 7  OBSERVED AND SIMULATED NITRATE CONCENTRATIONS

BABRAHAM

mgNO3/l

Figure 10  OBSERVED AND SIMULATED NITRATE CONCENTRATIONS

FLLEM DYKE

\( \text{mg NO}_3/\text{l} \)

simulated (using mean recharge every year)

Figure 11  OBSERVED AND SIMULATED NITRATE CONCENTRATIONS

FLEAM DYKE

mgNO₃/l

simulated (variable recharge based on Incs 1/m²/year)
Figure 12  PREDICTED NITRATE CONCENTRATIONS

FLEAM DYKE

mgNO₃/1