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# AN INVESTIGATION OF COMPLEX SALINE GROUNDWATER PROBLEMS IN THE PERMO TRIASSIC SANDSTONES OF NORTH WEST ENGLAND

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## ABSTRACT

Long standing saline intrusion and connate saline groundwater problems are being studied in the Permo Triassic aquifers of North West England. This multi-disciplinary study is being carried out to provide data for the evaluation of aquifer management options for the protection of valuable water resources.

Major and minor ion chemistry determined from pore waters depth samples and pumped discharges are being examined in conjunction with isotope data. Geophysical logging and deep penetration surface resistivity techniques are helping to delineate saline water bodies. Packer tests down to depths of 400 metres are providing information on aquifer properties and saline water movement.

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## INTRODUCTION

Arenaceous rocks of Permo-Triassic age form the major aquifer in North West England and are the principal source of groundwater within the region (ref. 1). Groundwater development started in the early 1800's in and around the industrial centres of Liverpool and Manchester. Initially development was concentrated along the banks of the tidal River Mersey and saline intrusion was observed by 1850 (ref. 2). Inland, away from the tidal river, connate saline waters have been found thus adding to the problems of resource development.

Piecemeal development continued until 1963 when legislation was passed which brought development under control (ref. 3). An aquifer management policy (ref. 4) was formulated to control gross over pumping and bring it into balance with recharge. Despite reductions in pumping, salinity values have continued to rise and some 40% of the aquifer area is now affected (fig. 1).

In 1978 the Authority in conjunction with the University of Birmingham embarked on a five year programme of investigation designed to provide the information required to review the aquifer management policy and introduce measures to control contamination. The paper discusses the various methods and techniques being used in the study.

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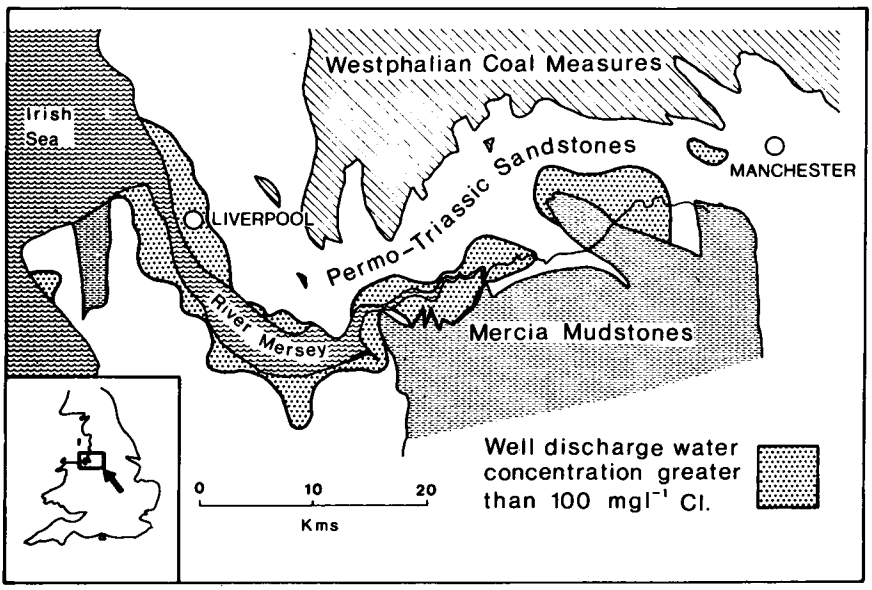


Fig. 1 Location of Study Area and extent of Saline Groundwater Problems

GEOLOGY

As a thorough understanding of the geology is an essential pre-requisite of any hydrogeological investigation all relevant aspects of the geology in the study area have been examined. The study area covers the northern part of the Cheshire Basin (ref. 5) which was formed tectonically in post Westphalian times and refolded in Tertiary times after it had been filled with Permian and Triassic sediments of a largely continental origin. Sandstone and mudstone of Permian age form the base of the sequence over most of the area (ref. 6). The overlying Sherwood Sandstone Group (ref. 7), which attains a thickness of 500m in places, forms the major aquifer, and Mercia Mudstones occupy the centre of the basin to the south of the study area. The aquifer has a regional dip to the south and is affected by normal faulting trending north to north west with subordinate east west faults.

Information provided by some 20 fully penetrating mineral exploration boreholes drilled in the last 4 years has helped to resolve many of the structural features within the sandstone thus providing a detailed picture of aquifer geometry (ref. 8). Whilst the aquifer is, in places, exposed at surface much of the outcrop area is covered with a wide range of glacial and post-glacial deposits (ref. 9). A comprehensive study of all borehole data has been used plot the distribution of superficial deposits and assessed their influence upon the rates of rainfall recharge.

AQUIFER CHARACTERISTICS

Field and laboratory methods are being employed to evaluate aquifer properties both to assess their influence on saline water movement and fulfil numerical modelling data requirements.

Pumping Tests

Constant rate and stepped drawdown pumping tests are being carried out at pumping station sites with observation boreholes to establish bulk permeability and evaluate overall aquifer behaviour. Data from the tests is being examined using radial flow modelling techniques (ref. 10) and results so far indicate an average bulk permeability of 2.5 m/d.

Laboratory Tests

The permeabilities of small plugs of unfissured core material are measured with a gas permeameter (ref. 11). Both vertical and horizontal permeability are being measured on samples of each lithofacies present in the sequence (ref. 12). Preliminary findings suggest average horizontal permeabilities of 0.7 m/d with an average anisotropy ratio of about 1:5 but reaching 1:100 in extreme cases.

Packer Testing

As there are obvious differences between laboratory and field permeabilities packer testing is being used to examine the influence of fissuring. During construction of a borehole (100m x 110mm) at Kenyon Junction (Fig. 2) water injection tests were carried out every 10m. using a single packer to isolate 2m. sections. Following drilling, caliper and closed circuit television logging revealed a number of fissures most of which were sub-horizontal and flow logging indicated a downward movement within the hole.

Injection tests using double packers (ref. 13) have been carried out over the full depth of the borehole. A standard test section of 3.5 metres has been used with a depth increment of 2.85 metres. A profile of the values obtained is shown on fig. 2 (ref. 14) which suggests that 85% of the transmissivity value ($90m^2/d$) could be attributable to fissure flow. Packer tests now taking place at other sites are confirming the importance of fissure flow and examining permeability variations throughout the succession.

Piezometer Tests

In the Kenyon Junction borehole piezometers have now been installed at various depths between bentonite seals to examine the effects of pumping from an adjacent borehole. The greatest reduction of head was observed in the piezometers at the same horizon as the pump intake in the adjacent borehole. The results are being analysed and compared with conventional pumping test data from the same site.

Partial Penetration Tests

The effects of partial penetration are being studied. Following the construction of the 200m borehole at Padgate (fig. 2) a second hole at a

distance of some 30m was drilled to a depth of 100m using air flush rotary methods. Drilling fluid leaving the hole, being equivalent to a well discharge, was monitored continuously. Throughout construction, many profiles of conductivity and differential temperature were measured in the 200m hole to identify horizons where flow was taking place. Flow was seen occurring only in those fissures above the level of the base of the "pumping well". Several fissured zones contributed to the flow in the hole, however their individual significance changed as the "pumping well" depth increased.

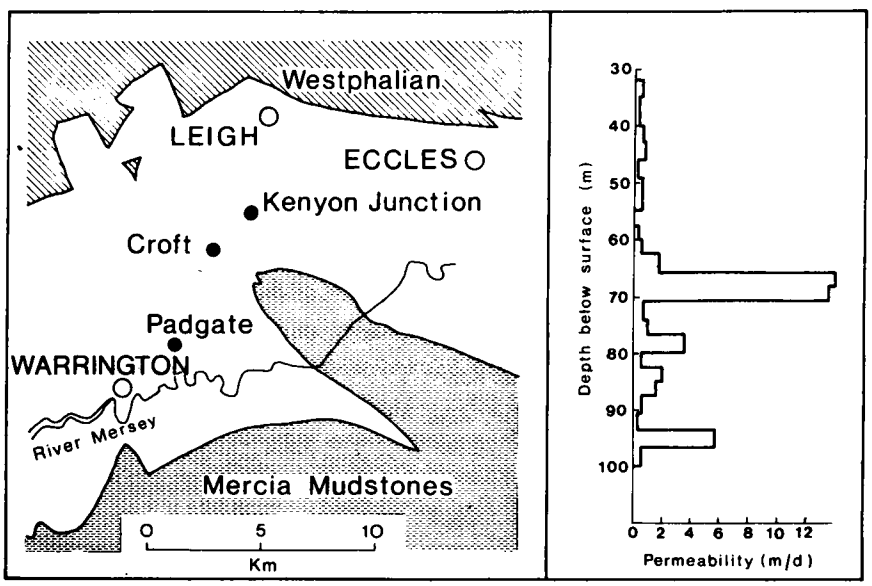


Fig. 2. Location of test sites and permeability profile at Kenyon Junction.

HYDROCHEMICAL STUDIES

Increasing salinity of pumped groundwater supplies is not restricted to sites adjacent to the coast or along the Mersey Estuary (fig. 1). Mineralised waters are present at depth, therefore boreholes (>300m.) are being sunk to examine the lateral and vertical distribution of the major and minor ion chemistry.

Geophysical Logging

Dual Laterolog (ref. 15) has proved a most useful tool in the identification of changes in formation water quality when used in mud-filled fully penetrating mineral exploration boreholes being drilled in the study area. These logs have confirmed the presence of saline water in the Sherwood Sandstone commonly at depths between 200-250m below surface over most the study area; that the change from 'fresh' to 'saline' groundwater occurs over a vertical section of some 30m; and that at depth the Permian sandstone generally contains highly saline water.

Surface Geophysics

Electrical resistivity sounding techniques using dipole-dipole configuration are being developed to aid mapping of the saline water bodies within the Sherwood Sandstone (ref. 16).

Isotope Data

Carbon 14 and tritium analyses have provided data on regional flow rates. In addition uranium-thorium analyses are proving useful in differentiating between modern and ancient saline waters. Tritium profiles are being measured to study recharge movement through argillaceous superficial deposits.

Porewater Chemistry

Boreholes constructed for the study have been drilled by rotary methods and cores (usually S.F. size) have been recovered using a double core barrel with fresh water or foam drilling fluid. Rhodamine dye has been used to indicate the extent to which drilling fluids have invaded cores. Uncontaminated porewaters are being extracted using centrifuge techniques (ref. 17). Conductivity of crushed core and distilled water mixes (ref. 18) are being used to draw up porewater salinity profiles and have proved a more reliable indicator than either monitoring of drilling returns or periodic fluid logging. The profiles are used to select cores for porewater extraction as critical horizons can be quickly identified thus reducing the number of samples requiring full chemical analysis.

Saline Water Movement in Response to Pumping

The influence of pumping wells on deep saline water is being investigated at two sites. At Padgate, (fig. 2) three test boreholes have been constructed to depths of 30, 100 and 200m. with saline water being penetrated at 140m. Whilst pumping the 100m. borehole changes in the mineralised water levels are monitored in the adjacent 200m. borehole. Tests are being carried out using packers to vary the effective depth of the hole to determine the factors which control the movement of saline groundwater. Although incomplete, the tests indicate that it is necessary to introduce packers in the 200m. borehole to prevent mineralised water flowing up the borehole itself and re-entering the aquifer at higher levels.

Differing levels of mineralised waters in the aquifer and boreholes have been observed in the Croft area (ref. 19) where over-pumping in the past 15 years has drawn up mineralised water some 100m. into pumping wells. The changes in chemistry and hydrostatic level of highly saline waters in the underlying Permian Sandstone are being examined by means of a standpipe inserted to a depth of 500m. with a packer set at 410m. in a nearby mineral exploration borehole.

## FURTHER WORK

There are many other aspects to the study including catchment analysis, Hele Shaw modelling of fresh and saline groundwater bodies and numerical modelling of regional groundwater flow. All aspects will be drawn together to form a basis for evaluation of aquifer management options to complete the study by 1984.

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## REFERENCES

1 North West Water, First Report of Survey of Water Management and Use (1978) 41-47.
2 Stephenson R., Report on the Supply of Water to the Town of Liverpool (1850) 1-89.
3 Brassington F.C., Controlled and Uncontrolled Groundwater Development. Brit. Assoc. Salford (1980)51.
4 Mersey & Weaver River Authority, Statement of Policy for Groundwater Management, Warrington (1973)17pp.
5 Colter V.S. & Barr K.W., Recent Developments in the Geology of the Irish Sea and Cheshire Basin, in Woodland A.W. (Ed) Petroleum and the Continental Shelf of North West Europe, Vol. I Geology Applied Sci Pub London (1975)61-73.
6 Smith D.B. et al, A Correlation of Permian Rocks of the British Isles, JL Geol. Soc. Lond., 130 (1974)1-45.
7 Warrington G. et al. A correlation of Triassic Rocks of the British Isles, Geol. Soc. Lond., Sp. Rep. No. 13 (1980)1-77.
8 Campbell J.E., Geological Structure of Investigation Area, in Saline Groundwater Investigation Phase I Seminar Report, Warrington (1980)10-15.
9 Grayson R.F., The Buried Bedrock Topography between Manchester and the Mersey Estuary MSc. Thesis, Univ. Manchester (1972).
10 Rushton K.R. and Redshaw S.C., Seepage and Groundwater Flow, Wiley (1979) 231-293.
11 American Petroleum Institute, Recommended Practice No. 27. A.P.I. Washington (1957)27pp.
12 Thompson D.B., Sedimentation of the Triassic (Scythian) Red Pebbly Sandstones in the Cheshire Basin and its Margins. Geol J. 7 (1970)183-261.
13 Pearson R. and Money M.S., Improvements in the Lugeon or Packer Permeability Test. Q JL Eng. geol. 10 (1977)221-241.
14 Walthall S. & Ingram J.A. Field Permeability Testing at Kenyon Junction, in Saline Groundwater Investigation Phase I Seminar Report, Warrington (1980) 33-44.
15 Schlumberger. Log Interpretation Vol.1 Principles, Paris, (1972)19-25.
16 Acworth R.I., The Development of Deep Penetration Resistivity Survey Techniques in Saline Groundwater Investigation Phase I Seminar Report, Warrington (1980) 26-32.
17 Barber C., Groundwater Sampling: The Extraction of Interstitial water from Cores of Rock and Sediment by High Speed Centrifuge. W.R.C. TR54 (1977)17pp.
18 American Petroleum Institute, Recommended Practice for Core Analysis, API RP40 (1960)52p.
19 Rushton K.R., Differing Positions of Saline Interfaces in Aquifers and Observation Boreholes, J. Hydrol. 48 (1980)185-189.