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GROUNDWATER CONTAMINATION BY LANDFILL LEACHATE: DISTRIBUTION OF CONTAMINANTS AND FACTORS AFFECTING POLLUTION PLUME DEVELOPMENT AT THREE SITES, UK

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INTRODUCTION

Following a desk study (ref. 1) of the water pollution hazards represented by almost 3000 landfill sites in England and Wales, the Water Research Centre and the Institute of Geological Sciences undertook detailed investigations of 20 waste disposal sites, as part of a continuing programme of research on the disposal of hazardous wastes by landfill, funded by the Department of the Environment (ref. 2).

This paper reviews groundwater pollution at three of the sites investigated, two situated on Triassic Sandstones and one within alluvial deposits overlying Triassic Marls. The nature of the pollution plumes and the factors controlling their development are discussed.

SITE INVESTIGATION TECHNIQUES

Detailed drilling programmes, to determine the lateral and vertical extent of contamination, were undertaken at each site, and core as well as groundwater samples were collected, allowing the extraction of pore fluid samples by high-speed centrifugation (ref. 3). In addition, groundwater profiles were obtained at one of the Triassic Sandstone sites, using an inflatable packer system (ref. 4) to isolate discrete horizons within the boreholes. Both surface and borehole geophysical logging techniques were utilized to aid the interpretation of local geology.

Details of the hydrogeology, geology, types of waste deposited, and groundwater contamination at each site are summarized in Table 1, and discussed in greater detail below.

RESULTS OF SITE INVESTIGATIONS

a) Coatham Stob

The disposal of chrome ore processing wastes (liquid and solid) at this site in a fissured dolerite dyke, has resulted in groundwater contamination with sodium, vanadium and hexavalent chromium, and has produced a recharge mound below the waste lagoon. Leachate from the wastes, containing 5000-10 000 mg Cr/l has moved

TABLE 1

Summary of sites investigated

	Coatham Stob	Villa Farm	Hammerwich
Operational period	1947 - still operational	1945 - still operational	1961-1964
Site geology	Quarry in dolerite dyke intruding Triassic sandstones (sandstone groundwater confined by boulder clay away from dyke margins)	Sub-water table excavation in quaternary lacustrine sands and clays underlain by boulder clays and Triassic Marls	Sandpit in poorly cemented Triassic sandstone, some marly bands
Site area	6000 m^2	5000 m^2	315 m^2
Unsaturated zone depth	6 m	Absent	15 m
Groundwater flow	Fissure and intergranular	Intergranular in superficial deposits	Intergranular (mainly)
Wastes and rates of disposal	Chromite ore processing sludge (7850 tonnes soluble Cr VI, 1947-1978)	7000 m^3/annum since 1971. Industrial liquid wastes e.g. cutting oils, metallic sludges, pickle liquors and alkaline cleaning fluids	Crude domestic and inert wastes. 50 tonnes drummed heat-treatment wastes containing barium cyanide
Identified major contaminants and indicators of contamination	Cr (VI) Na V	TOC, phenol, Na, Cl, SO_4, NO_3, Fe, Mn, and some heavy metals e.g. Ni. Reduced DO, Eh	TOC, phenol, cyanide, thiocyanate, Fe, Mn, alkalinity, reduced DO, increased temperature
Major controls on pollution plume development	Vertical movement in fissures - movement into high-permeability zones with dispersion in sandstones	Density stratification at aquifer base. Redox control of Fe, Mn, heavy metals and SO_4, NO_3	Dilution and dispersion in upper 5-10 m of saturated zone

TOC - Total organic carbon   DO - Dissolved oxygen   Eh - Redox potential vertically into baked and fissured Triassic Sandstone marginal to the dyke, to depths of at least 100 m possibly as a result of a density contrast between leachate and groundwater. Although the shape of the pollution plume in plan is determined by the local groundwater gradient, the vertical profile (Fig. 1) is controlled by variations in permeability of the sandstones beyond the baked contact zone. Greater movement has occurred along a more permeable horizon approximately 30 m below the water table, with chromium being detected up to 250 m downgradient of the site.

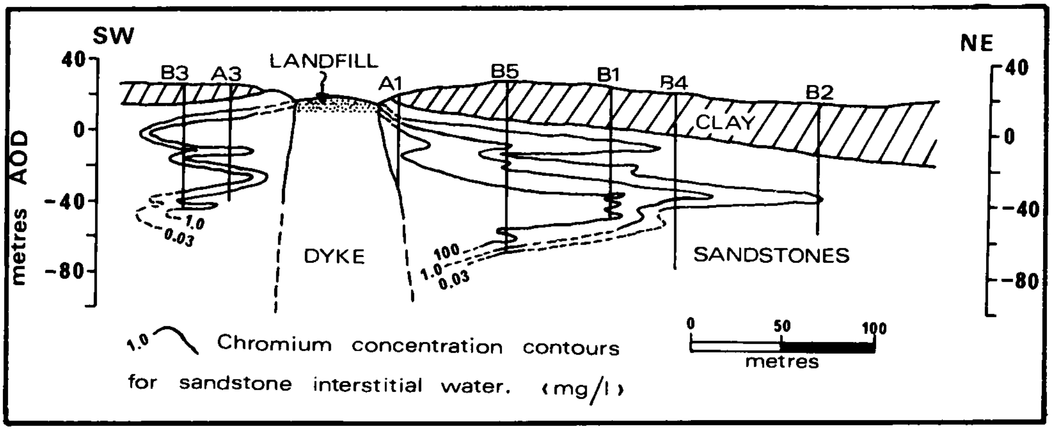

Fig. 1. Vertical section across landfill site, Coatham Stob, Cleveland, showing extent of contamination of interstitial water in sandstone aquifer.

Although an impermeable liner was placed over the waste in 1976, there has been little evidence of any decay of the recharge mound. However, contamination of the groundwater in the sandstone has gradually decreased, with a 55% reduction in chromium concentrations in the most permeable horizons, over a period of three years. There is little evidence of any attenuation, of Cr (VI), other than by dispersion and dilution, at this site.

b) Villa Farm

In contrast to Coatham Stob, the Villa Farm disposal site is in direct hydraulic continuity with local groundwater. The site consists of a series of lagoons excavated below the water table in a sequence of Quaternary lacustrine sands and clays. These are underlain by glacial boulder clays and Triassic Marls which restrict downward migration. Although disposal of a variety of industrial wastes, including cutting oils and metallic sludges, has formed a recharge mound about 3 m above the natural water table, the accumulation of sludge reduces outflow and leachate escapes preferentially from the base of the site when the lagoons are dredged.

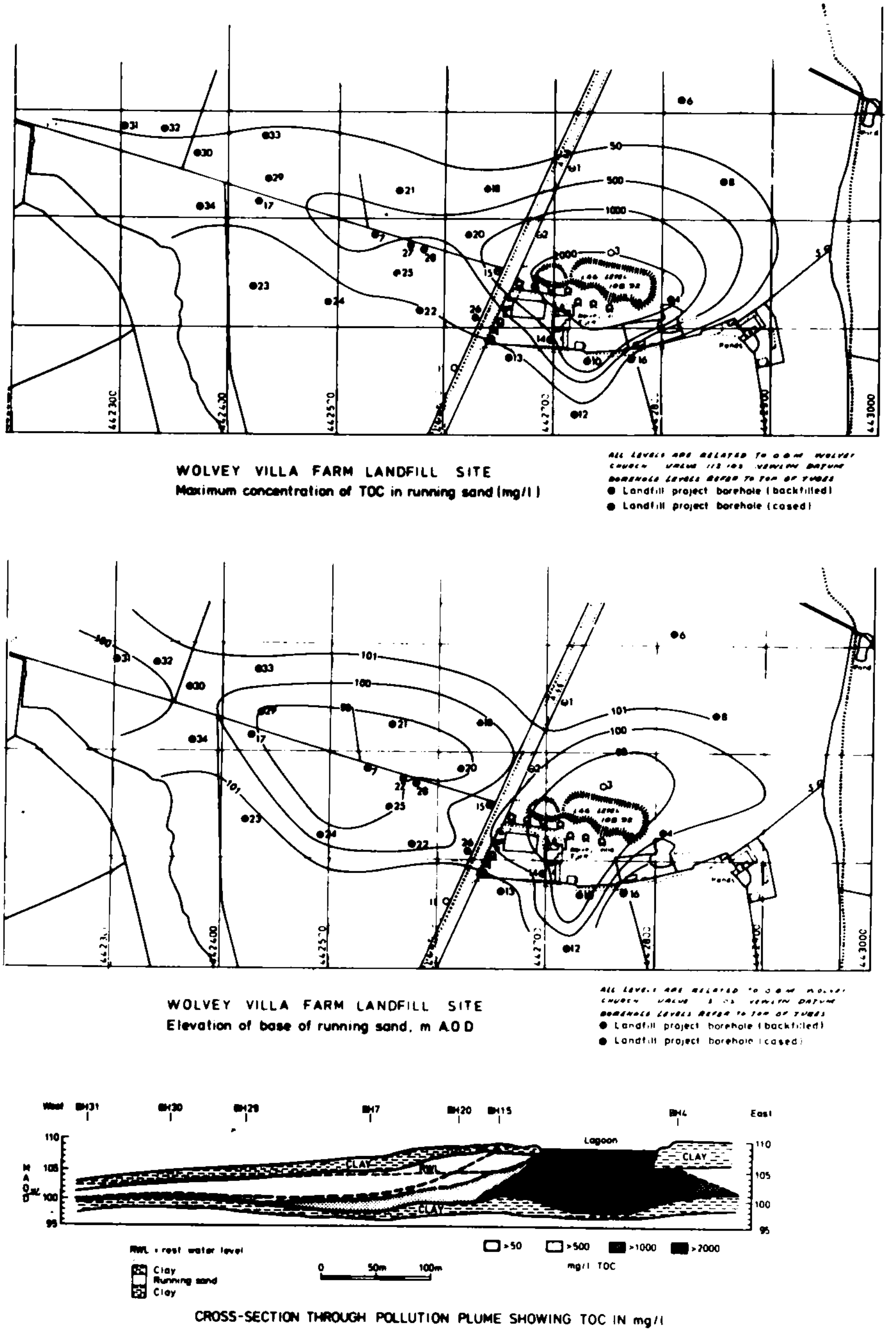

Fig. 2. Site detail of Villa Farm landfill, Wolvey.

Running-sand fills a series of scour hollows (one of which underlies the lagoon) developed on the surface of a clay horizon some 10 m below ground level. Wastes stratify at the base of the sand and fill up one hollow before spilling over to the next (Fig. 2). Density effects and the elevation of the clay surface are, therefore, major controls on leachate migration, and restrict dispersion of the pollution plume.

However, reductions in the concentrations of total organic carbon (TOC), sulphate, nitrate, and heavy metals have been significant and can be related to the development of three geochemically distinct zones: (i) a highly polluted region overlying the clay base, and close to the site, characterised by sulphate and nitrate reduction, low redox potentials and heavy-metal attenuation, probably as sulphides; (ii) an intermediate zone with little sulphate reduction and significant remobilisation of sediment iron and manganese, and intermediate redox potentials; (iii) a relatively unpolluted zone characterised by rising dissolved oxygen, low iron and manganese concentrations (probably due to hydroxide precipitation), and higher redox potentials. Conservative species such as the chloride ion are unaffected by these processes.

The extent of the pollution plume has also been traced by analysis of gas trapped between the water table and a surface clay layer. Carbon dioxide and methane concentrations correlate well with the distribution of the intermediate and highly reducing zones, following the advance of the pollution front.

c) Hammerwich

In comparison with Coatham Stob the second Triassic Sandstone site at Hammerwich is underlain by an unsaturated zone 15-m thick which limits the release of pollutants into the saturated zone and offers potential for biological and chemical attenuation. Contamination extends to a depth of 5-10 m below the water table and the composition of the pollution plume is similar to that at Villa Farm, with additional contamination by cyanide and thiocyanate (Table 1). Although distinct zones of contamination have not been recognised, sampling of groundwater from different depths suggests that the plume which has developed down hydraulic gradient (Fig. 3) is relatively stable, with small cyclic variations, possibly in response to varying hydrological conditions. Attenuation of pollutants in the saturated zone is considered to be due to dispersion.

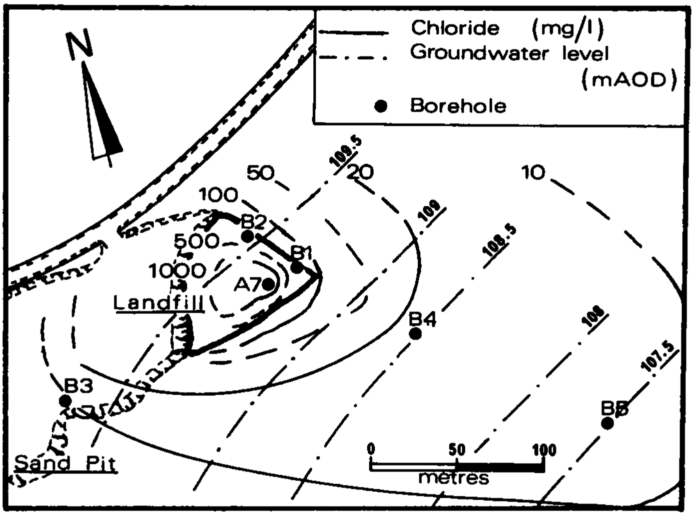

Fig. 3. Hammerwich landfill, groundwater levels and distribution of chloride as an indicator of pollution of groundwater around the site.

CONCLUSIONS

The generation of large volumes of leachate from liquid waste disposal at Coatham Stob and Villa Farm has led to acute groundwater contamination; significant movement of leachate within the saturated zone has also taken place at both sites. This contrasts with the relatively small plume of contamination at the Hammerwich site, which does not receive liquid wastes.

Preferential migration of contaminants along zones of high permeability, and stratification as a result of density contrast with groundwater, may result in poor dispersion of contaminants. Although dispersion is the main attenuating factor in the saturated zone at Coatham Stob and Hammerwich, chemical and biochemical processes in the saturated zone at Villa Farm (and possibly in the unsaturated zone at Hammerwich) have reduced the effects of pollution of groundwater by landfill leachate.

The wide range of controls on pollution plume development underlines the need for detailed hydrogeological assessment prior to waste disposal, particularly as groundwater contamination is not a short-lived phenomenon.

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