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THE IMPACT OF POINT SOURCE POLLUTION ON GROUNDWATER QUALITY

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Groundwater pollution point, or local, sources may differ in intensity, extent, duration and the degree to which effective control may be maintained from pollution due to diffuse sources. The characteristics of pollution from the principal types of point source pollution are examined and the extent to which management may ameliorate their environmental impact is discussed, particularly in the light of the apparently antagonistic 'contain and concentrate' and 'dilute and disperse' philosophies. The state of knowledge of the various physical, chemical and biological processes which control the generation, migration and attenuation of leachates is reviewed and suggestions made for future research.

INTRODUCTION

Point sources of pollution are differentiated primarily from diffuse sources by the precision with which the source of contamination can be identified. The discharge of wastes to landfill sites, the subsurface injection of wastes via deep boreholes and the disposal of effluents by irrigation to sacrificial land constitute the major, persistent sources of point pollution. Accidental spillage of potentially polluting substances from road or rail transport and the leakage of liquids stored in tanks or in transit in pipelines provide intermittent examples, which may, however prove to be of considerable local importance. In contrast, pollution originating from changes in farming practice, the application of agrichemicals and the use of sewage sludge as fertiliser supplements (ref 1) represent diffuse pollution sources. However, an effect similar to diffuse source pollution may arise from the action of a large number of small point sources, as for example in the case of chromium pollution from small electroplating works effluents on the Chalk aquifer (ref 2) or land pollution from ceramics factories of an alluvial aquifer (ref 3).

CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF POLLUTION FROM POINT SOURCES

The principal characteristics of the main forms of wastes, effluents and accidental discharges which give rise to point source pollution are summarised in Table 1.

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TABLE 1

Characteristics of pollutant sources
(data from reference 4 unless otherwise stated)

Source	Potential characteristics of leachate/effluent	Typical rate of effluent or solid waste production
Domestic and commercial wastes	High sulphate, chloride, ammonia, BOD, TOC and suspended solids from fresh wastes (ref 5). Bacterial impurities. In humid climates leachate composition changes with time; initial TOC mainly volatile fatty acids (acetic, butyric, proprionic), subsequently changing to high molecular weight organics (humic substances, carbohydrates). Period of change c. 5 to 10 years after deposition of wastes in humid, temperate regions. Leachate content of wastes c. 2.30 kg BOD/tonne, 1.50 kg TOC/tonne, 1.20 kg Cl/tonne, 0.80 kg SO_4-S/tonne, 0.30 kg NH_3-N/tonne (ref 6)	0.2 to 0.4 tonnes/yr/person Characteristic landfill size 10^4 to 10^8 m^3 Rate of leachate production dependent on climate
Industrial solid wastes	Variable. Leachates generally similar in composition to effluent or sludge from some process (see below)	0.3 tonnes/yr/person in industralised societies Industrial landfills 10^4 - 10^6 m^3
Industrial effluents and sludges		
Food and drink manufacturing	High BOD. Suspended solids often high, colloidal and dissolved organic substances. Odours.	10^3 - 10^7 m^3/yr/factory
Textile and clothing	High suspended solids. High BOD. Alkaline effluent.	10^4 - 10^6 m^3/yr/factory
Tanneries	High BOD. Total Solids, Hardness, chlorides, sulphides, chromium.	10^3 - 10^6 m^3/yr/factory
Chemical and petrochemical	High BOD. Variable or low pH. High organic residues, sulphur compounds, suspended solids.	10^5 - 10^9 m^3/yr/factory
Foundries	Low pH. High suspended solids, phenols, oil.	10^7 - 10^9 m^3/yr/factory
Plating and metal finishing	Low pH. High content of toxic heavy metals, sometimes as sludges.	
Engineering works	High suspended solids, soluble cutting oils, trace heavy metals. Variable BOD, pH.	10^4 - 10^7 m^3/yr/factory

TABLE 1 (continued)

Source	Potential characteristics of leachate/effluent	Typical rate of effluent or solid waste production
Power generation (thermal)	Pulverised fuel ash. Up to 2% by weight soluble constituents, sulphate. May contain concentrations of Germanium and Selenium (ref 7)	10^4 - 10^5 tonnes/yr/ generating station
	Fly ash and flue gas scrubber sludges. Finely particulate, containing disseminated heavy metals. Sludges of low pH unless neutralised by lime additions (ref 8).	
Mining	Coal Mine Drainage. High total dissolved solids, suspended solids. Iron. Often acid. May contain high chlorides from connate water.	10^5 - 10^7 m^3/yr/mine
	Solid Colliery Wastes. Leachate similar to mine drainage waters.	10^5 - 10^5 tonnes/yr of wastes, per colliery. Quantity of leachate dependent on climate
	Base Metal Mining. High total suspended solids. Possibly low pH. High sulphates from oxidation of sulphides. Dissolved and particulate metals. Washing and mineral dressing waters may contain organic flocculants.	10^5 - 10^7 tonnes/yr wastes per mine. Quantity of leachate dependent on climate
Human wastes		
Septic tank drainage	Suspended solids 100 - 300 mg/l BOD 50 - 400 mg/l TOC 100 - 300 mg/l Total solids 300 - 600 mg/l Ammonia 20 - 40 mg Chloride 100 - 200 mg Cl/l High faecal coliforms and streptococci	40 - 60 m^3/yr/person (Assuming connection to water-flush toilet system)
Sewage sludge, digested	Solids 4 - 7% Organic matter 2 - 4% Heavy metals if mixed with storm water discharges. High Al, P, K, N (as NH_3)	10^4 - 10^5 m^3/yr/works
Animal wastes, effluents from intensive stock yards	Suspended solids 10 000 mg/l BOD 5000 mg/l Total N 2000 mg/l Faecal streptococci and coliforms high.	Cattle units 10^3-10^5 m^3/yr Pig units 10^3-10^4 m^3/yr Poultry units 10^4-10^5 m^3/yr

TABLE 1 (continued)

Source	Potential characteristics of leachate/effluent	Typical rate of effluent or solid waste productic
Silage	High suspended solids, BOD 1-6 × 10^4 mg/l Organic components - carbo-hydrates, phenols.	0.2 - 0.4 m^3/tonne
Accidental spillages and leakages from storage tanks and pipe-lines	Various liquids in transit, hydrocarbons, petrochemicals, acids, alkalis, solvents. Liquids may enter surface drains or soak aways.	Generally between 10 and 10^3 m^3 per incident

Following the early experimental studies by the Ministry of Housing and Local Government, London (ref 6) and the description of the pollution of a shallow alluvial aquifer by leachate derived from domestic wastes by Exler (ref 9), other experimental and site studies have been reported and reviewed by Remson *et al.* (ref 10), Waterton *et al.* (ref 11), Qasim and Burchinal (ref 12), Zanoni (ref 13), Rovers and Farquhar (refs 14,15), Pohland and Engelbrecht (ref 16) and Robinson and Maris (ref 5). The high organic and inorganic (particularly Cl, NH_3, SO_4) levels in leachates from fresh wastes give rise to anaerobic conditions within any unsaturated zone beneath the landfill and within the groundwater. A plume of contamined water characterised by low dissolved oxygen and high chloride, sulphate and ammonia concentrations typically extends in the direction of groundwater movement. The rate of attenuation of polluting contaminants is dependent on the hydrogeological and geochemical characteristics of the aquifer system. The distance from the polluting source at which concentrations are reduced to background values may vary seasonally in response to changing groundwater regimes, producing a plume in dynamic equilibrium (ref 17) with the local groundwater system.

The effects of leaching from industrial waste disposals in the United States has been reviewed by Miller *et al.* (ref 18) where a survey of 50 sites provided 43 examples of groundwater contamination. A report on the first phase of a co-ordinated programme of site investigations and experimental studies in the United Kingdom, by the Department of the Environment, London, (ref 19) has indicated only limited contamination of groundwaters by compounds specific to industrial wastes at sites on permeable strata. An exception was found in the case of the disposal of chromium ore sludges to a site on the Triassic Sandstone of north-eastern England, where pollution by hexavalent chromium was detected at distances of up to 250 m from the site (Barber *et al.* (ref 20)). Similar pollution, arising from the discharge of plating effluents to lagoons has been reported by Perlmutter and Lieber (ref 21) from a gravel aquifer at Long Island, New York.

Large quantities of mine wastes accompany the extraction of coal, approximately 50 million tonnes of argillaceous spoil being produced annually in the United Kingdom (ref 22), of which a high proportion are deposited in landfill. Subaerial weathering of disseminated pyrite in the shales produces a leachate rich in chloride, sulphate, iron and manganese, which may give rise to groundwater contamination of the type reported by Nicholls (ref 23) from the Doncaster area, England, where the total hardness and chloride concentrations in Triassic Sandstone groundwater was increased from background values of 126 mg/l and 13 mg/l respectively in 1919, to maxima of 2060 mg/l and 2925 mg/l in 1965. The drainage water pumped from mines may also be highly polluting with respect to inorganic component and Headworth *et al.* (ref 24) have recorded the effects of the discharge of drainage water, over the period 1907 to 1974, onto the Chalk of East Kent, UK. An estimated 318 000 tonnes of chloride was discharged, contaminating groundwater resources over an area of 27 km^2, with chloride concentrations reaching 5000 mg/l locally.

Leakage from septic tank drainage and rivers has been reported to give rise to groundwater pollution by inorganic contaminants and bacteria in both the United States and the United Kingdom (refs 21,25), whilst seepage from cesspools was identified as a source of bacterial and ammoniacal contamination of Chalk groundwater in southern England as long ago as 1886 (ref 26). Approximately 480 000 tonnes of sewage sludge are deposited annually in landfills in the United Kingdom (ref 27), with a similar quantity applied as a fertiliser supplement to agricultural land. Investigations by Edworthy *et al.* (ref 28) of the agricultural use of sludge have indicated that heavy metal ions present in the sludge are strongly retained within the upper layers of soils, but that high application rates, which could approach the values characteristic of disposal to landfill or sacrificial land, may significally increase the rate of nitrate leaching to groundwater. A global survey of the effects of sewage effluent spreading on groundwater quality has been completed by Tahal (ref 29). The beneficial effect of infiltration of effluents has been considered by Bouwer (ref 30), McNabb *et al.* (ref 31) and Tahal (ref 29). The migration of pathogens from effluents, sludges and domestic wastes have been reported by Drewry and Eliassen (ref 32), Romero (ref 33), Liu *et al.* (ref 34) and Gillies (ref 35), whilst a review of the association between effluent recharge and infection by water-borne agents has been provided by Cooper (ref 36). The results of investigations of effluent disposals to the major United Kingdom aquifers have been reported by Baxter and Edworthy (ref 37) and Baxter *et al.* (ref 38), who found evidence of significant attenuation of pathogens and heavy metals during infiltration, but increases in the concentrations of mobile, conservative contaminants such as chloride in the underlying groundwater.

The problems of the protection of groundwater from pollution by hydrocarbons has been recently reviewed by Concawe (ref 39), who propose a variety of landfill management techniques to prevent contamination by waste oils. Accidental spillage and leakages may cause serious local groundwater quality problems as a result of the very low concentrations of soluble hydrocarbons necessary to produce objectionable tastes and odours in water supplies (refs 40,41). Oil residues may remain within the ground for a considerable period of time (ref 42), rendering difficult and expensive efforts to rehabilitate the aquifer. Hoare *et al.* (ref 43) have reported an incident on the Chalk of southern England where only 15 per cent of a spillage of 50 m^3 of aviation kerosene was recovered by scavenge pumping and the use of oil-absorbent mops over a twelve month period.

THE EFFECTS OF PHYSICAL, GEOCHEMICAL AND BIOLOGICAL PROCESSES ON GROUNDWATER POLLUTION

The process which may ameliorate the composition of polluted groundwaters (Table 2) have been the subject of thorough discussion and review by Langmuir (ref 44), Matthes (ref 45), Edmunds (ref 46), Jackson *et al.* (ref 47) and, particularly with reference to radionuclides, by Jackson and Inch (ref 48). The effectiveness of these processes, as reported from co-ordinated studies in the United Kingdom (ref 19) are discussed briefly.

TABLE 2

Mechanisms controlling attenuation

Physical	Geochemical	Biological
Dispersion	solution-precipitation	Decay and respiration
Filtration	acid-base reactions	Cell synthesis
Volatilisation	oxidation-reduction	
Gas exchange	complexation	
	adsorption-desorption	

Experimental determinations of dispersion coefficients were not undertaken as part of the research programme, but evidence of the effect of the mechanism was noted at sites on both Chalk (ref 27) and Triassic Sandstone (ref 20) aquifers, where the concentration of stable, mobile components of leachate was reduced to background levels within a short distance of the pollution source. Specific identification of filtration as a mechanism was not sought, because of the difficulties of distinguishing the effect from adsorption. However, evidence of the efficiency of pathogen removal during infiltration has been obtained from related research programmes in the United Kingdom (refs 37,38). The conversion of certain wastes to volatile products was detected at three sites by the presence of methane, carbon dioxide and hydrogen sulphide in borehole atmospheres. Evidence of the volatilisation of elemental mercury, from a site containing waste fluorescent lighting tubes, was recorded by the presence of up to 0.2 mg Hlg/m^3 in the atmosphere of a trench in the wastes. Hydrogen cyanide gas was detected in boreholes penetrating a disposal site containing heat-treatment wastes and in a pilot-scale simulated landfill containing the same material. Measurement of the oxygen content of borehole atmospheres indicated that at sites on intergranular flow aquifers, anoxic conditions were established in the unsaturated and saturated zones, with only slow gas exchange, but that more effective replenishment was active at sites in fissured strata. Dissolved oxygen concentrations of 2-16 per cent were recorded within a glacial sand aquifer, whilst a value of about 36 per cent was measured in fissured Chalk strata.

The higher solubility of chlorinated solvents in oil than water was found to concentrate the solvents in the oil phase at two sites examined. Evidence of the precipitation of heavy metals, including mercury, as sulphides was recorded from the anaerobic interiors of landfills at two sites, whilst a sulphide sludge was recovered from the base of a simulated landfill containing added metal hydroxide sludge and operated under anaerobic conditions.

Enhanced levels of calcium, magnesium and ions were detected in porewaters from beneath a lagoon of low pH liquid wastes at a site, in Scotland, on Coal Measures sandstones with a sideritic matrix. A domestic waste substrate onto which liquid acid and alkali wastes were deposited was examined at a site on the Thames estuary. The pH of interstitial waters was in the range 7.7-8.5, indicating a high waste buffering capacity.

The products of redox reaction, in the form of ferric hydroxide slime, were noted on borehole casings at the water table at the Coal Measures site in Scotland. The results of complex reactions, including redox, formed a deposit with concentrations of Al, Ba, Cr, Cu, Fe, K, Mn, Ni, Pb and Zn significantly above background values on the walls of fissures in the unsaturated zone of a Chalk site.

Indications that complexation limited the mobility of cyanide, by the formation of a sparingly soluble precipitate of manganous ferro-cyanide, were recorded from a site which had received heat treatment wastes containing sodium cyanide, on the Triassic Sandstone in the Midlands of England. Pilot-scale simulated landfill experiments including a similar heat treatment waste provided evidence of the solubilisation of heavy metals by complex formation.

Evidence of significant adsorption of mercury onto montmorillonite in clays was recorded from site investigations, with calcium ions being displaced as a 'hardness halo'. Lysimeter experiments on the migration of heavy metal ions from synthetic leachate showed lead to be most strongly adsorbed, requiring only 1.5 kg of Lower Greensand (Cretaceous) to immobilise 1 gram of metal, whilst nickel (7.6 kg/gm) was most mobile. Chromium, copper, zinc, cadmium and mercury were intermediate in their behaviour.

The presence of short chain carboxylic acids in leachates and gases such as methane and carbon dioxide in borehole atmospheres were indicative of biological activity within the putrescible portion of wastes. Identification of microbial action in the unsaturated zone was made at one site, on fissured Chalk. Attenuation of TOC from 3000 mg/l to 100 mg/l was recorded at between 7 and 11 metre depth, in a zone of partial aeration.

CONCLUSIONS

Although point sources of pollution may, undoubtedly, threaten the quality of groundwater resources, investigations in the United Kingdom have suggested that the impact of leachates migrating from 'dilute and disperse' sites may be reduced to acceptable levels by proper site selection and waste management. Particular emphasis should be placed on determining the hydrogeological characteristics of a proposed site, including the presence of an unsaturated zone with leachate retarding properties, the degree of dilution effect by groundwater underflows and methods of waste emplacement designed to minimise leachate production. If such objectives are obtainable, the problems of leachate collection, treatment and disposal associated with 'containment' sites (ref 5) may be avoided.

In order to achieve reliable comments of potential sites, it is suggested that further information is required in the following areas:

(1) the effectiveness of leachate control measures by site management - by collaboration between waste disposal engineers and hydrogeologists and geochemists,
(2) the co-disposal of industrial with domestic wastes, to take advantage of the attenuating processes active in domestic substrates, and
(3) the role of microbial mediation in the unsaturated and saturated zones of aquifers in leachate attenuation.

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REFERENCES

1. D.B. Oakes, C.P. Young and S.S.D. Foster. Paper to International Symposium on Groundwater Quality, Noordwijkerhout, Netherlands, 23-27 March 1981.
2. J.-Y. Caous, M. Caudron and D. Dumont. In Proc. Colloque Regional-Hydrogeologie de la craie du bassin de Paris. Rouen 25-26 May 1978, BRGM, Orleans, 1978, pp. 89-94.
3. M. Pellegrini and A. Zavatti. In R.E. Jackson (Ed), Aquifer Contamination and Protection, UNESCO, Paris, in press.
4. R.G. Bond, C.P. Straub and R. Prober (Eds). Handbook of environmental control, Vol. IV, wastewater: treatment and disposal. C.R.C. Press, Cleveland, Ohio, 1974.
5. H.D. Robinson and P.J. Maris. Water Research Centre Technical Report TR 108, The Centre, Medmenham, UK, 1979.
6. Ministry of Housing and Local Government. Pollution of water by tipped refuse. Report of the Technical Committee on the Experimental Disposal of House Refuse in Wet and Dry Pits, HMSO, London, 1961.
7. C.C. Coutant, C.S. Wasserman, M.S. Chung, D.B. Rubin and M. Manning. J. Wat. Poll. Control Fed. 50 (1978) 747-753.
8. D.R. Dreasden, E.S. Gladney, J.W. Owens, B.L. Perkins, C.L. Wienke and L.E. Wangen. Environ. Sci. Technol., 11 (1977) 1017-1019.
9. H.J. Exler. In J.A. Cole (Ed), Proc. Water Research Assoc. Conf. Groundwater Pollution in Europe, Reading, September 1972. Water Information Center Inc., New York, 1974, pp. 215-241.
10. I. Remson, A. Fungaroli and A. Lawrence. J. Sanit. Eng. Div., Proc. Am. Soc. Civil Engrs., 94 (1968) 307-317.
11. T. Waterton, R.D. MacLean, A.S. Davison and W.S. Holden. Wat. Treat. Exam., 18 (1969) 15-69.
12. S.R. Qasim and J.C. Burchinal. J. Wat. Poll. Control Fed., 42 (1970) 371-379.
13. A.E. Zanoni. Ground Water, 10 (1972) 3-16.
14. F.A. Rovers and G.J. Farquhar. Sanitary landfill study, Vol. 2, Effects of season on landfill leachate and gas production. Univ. Waterloo Res. Inst., Ontario, Canada, 1972.
15. F.A. Rovers and G.J. Farquhar. J. Environ. Engng. Div., ASCE, 99 (1973) 671-690.
16. F.G. Pohland and R.S. Engelbrecht. Impact of sanitary landfills: an overview of environmental factors and control alternatives. Am. Paper Inst. 1976.
17. P. Millbank. Surveyor, 6 August (1976) 28-30.
18. D. Miller, O. Braids and W. Walker. US EPA Rept., EPA 68-01-2966, 1977.
19. Department of the Environment. Co-operative programme of research on the behaviour of hazardous waste in landfill sites: Final report of the Policy Review Committee, HMSO, London, 1978.
20. C. Barber, C.P. Young, N.C. Blakey, C.A.M. Ross and G.M. Williams. Paper to Int. Symp. Groundwater Qual. Noordwijkerhout, Netherlands, 23-27 March 1981.
21. N.M. Perlmutter and M. Lieber. US Geol. Surv. Wat. Supply Pap. 1879-G, 1970.
22. H.G. Headworth and W.B. Wilkinson. In W.B. Wilkinson (Ed), Proc. Wat. Res. Centre Conf., Groundwater Quality - Measurement, Prediction and Protection, Reading, England, 6-8 September 1976. The Centre, Medmenham, 1977, pp. 780-817.
23. G.D. Nicholls. In J.A. Cole (Ed), Proc. Wat. Res. Assoc. Conf. Groundwater Pollution in Europe, Reading, England, September 1972, Water Information Center Inc., New York, 1974, pp.116-125.
24. H.G. Headworth, S. Puri and B.H. Rampling. Q. J. Eng. Geol., London, 3 (1980) 105-117.
25. J.M. Shepherd. Proc. Soc. Wat. Treat. Exam. 11 (1962) 12-16.
26. W. Whitaker. The Water Supply of Kent, with records of sinkings and borings. Mem. Geol. Surv. England and Wales, HMSO, London, 1908.
27. C.P. Young and C. Barber. In Proc. Soc. Chem. Ind. Conf. Reclamation of Contaminated Land, Eastbourne, 22-25 October 1979, Soc. Chem. Ind., London (1980), paper D5/1.
28. K.J. Edworthy, W.B. Wilkinson and C.P. Young. Prog. Wat. Tech. 10 (1978) 479-493.

29. Tahal Ltd. Advanced trêatment, groundwater recharge and re-use of municipal water. Don Region and Winter Operation. Report for Mekerot Water Co. Ltd, 1977.
30. H. Bouwer. Ground Water 12 (1974) 140-147.
31. J.F. McNabb, W.J. Dunlop and J.W. Keeley. US EPA Report No EPA-600/8-77-010, 1977.
32. W.A. Drewry and R. Eliassen. J. Wat. Poll. Control Fed., 40 (1968) 257-271.
33. J.C. Romero. Ground Water, 8 (1970) 37-48.
34. D. Liu, J. Stephenson and K. Kwasniawska. Can. Res., 8 (1975) 21-22.
35. N.P. Gillies. Ground Water, 14 (1976).
36. R.C. Cooper. J. Environ. Engng Div. ASCE, 103 (1977) 37-47.
37. K.M. Baxter and K.J. Edworthy. Int. Conf. Artificial Recharge, Dortmund, German Federal Republic, 1979.
38. K.M. Baxter, K.J. Edworthy, H.A.C. Montgomery and M.J. Beard. Paper to Int. Symp. Groundwater Qual. Noordwijkerhout, Netherlands, 23-27 March, 1981.
39. CONCAWE. Report No. 3/79, Concawe, The Hague, 1979.
40. D.E. Williams and D.G. Wilder. Ground Water, 9 (1971) 50-56.
41. H.E. Smith. Proc. Soc. Wat. Treat. Exam. 11 (1962) 32-33.
42. D.N. Diezt. H_2O, 4 (1978) 77-80.
43. M.J. Hoare, J.W. Eastwood and S. Brown. Surveyor 24 May 1979, 12-13.
44. D. Langmuir. Earth Miner. Sci. 42 (1972) 9-13.
45. G. Matthes. Hydrol. Sci. Bull. 21 (1976) 617-628.
46. W.M. Edmunds. In W.B. Wilkinson (Ed), Proc. Wat. Res. Centre Conf. Groundwater Quality - Measurement, Prediction and Protection, Reading, England, 6-8 September 1976, The Centre, Medmenham, UK, 1977, pp. 115-147.
47. R.E. Jackson, W.F. Merrit, D.R. Champ, J, Gulens and K.J. Inch. In The Use of Nuclear Techniques in Water Pollution Studies, IAEA, Vienna, in press.
48. R.E. Jackson and K.J. Inch. Nat. Hydrol. Res. Inst., Paper No. 7, Sci. Series No. 104, NHRI, Ottawa, Canada, 1980.