

EFFECTS OF DISCHARGING SEWAGE TO THE CHALK

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ABSTRACT

The paper describes a water quality investigation at Whitchurch, U.K., where 0.6 Ml/d of raw sewage have been discharged to a chalk aquifer for many years. Partial removal of dissolved BOD, nitrogen, phosphate, and organic carbon occurs in the unsaturated zone of 8-10 m depth. Partial removal of bacteria and viruses has also been observed. The descent to the water table has been shown by a tracer method to take approximately 18 hours. Analysis of the interstitial gas suggests a heterogeneous system in which anaerobic and aerobic bacterial action proceed simultaneously in the unsaturated zone.

INTRODUCTION

The volume of effluent discharged daily to the ground in the U.K. is estimated to be more than 100 Ml, about 42% of which is within the outcrop area of the Chalk aquifer. In the Southern Water Authority's area over 70% of the public water supply is groundwater and in the Thames and Anglian Water Authorities, about 50%. These supplies are vital both regionally and locally and it is essential to protect them from contamination. The capacity of aquifers to improve effluent quality is known to be considerable under ideal conditions but where hydrogeological factors have not been properly taken into account the potential hazards are great. There is at least one case in the U.K. where a groundwater source used for public supply has had to be shut down because of the effects of effluent recharge on water quality.

The programme of research carried out by SWA since 1975 and by WRC since 1976 has been carried out principally to determine the long-term effectiveness of aquifers for improving the quality of sewage and effluent. The quantitative effects of recharge on the aquifer and "travel times" in the aquifer have also been studied. The overall objective has been to establish aquifer management guidelines and to identify situations in which the recharge of effluent is to be discouraged.

The world-wide extent of the practice is reviewed in a report by Tahal (1) in which the importance of infiltration rate or hydraulic loading to the effectiveness of the process is stressed. Within the UK, research has been rather limited though relevant studies have been carried out by Satchell and Edworthy (2) and Beard and Montgomery (3). Reports of work related to this project have also been prepared (4,5).

WHITCHURCH RECHARGE SITE

The site (Fig.1) is located on the side of a dry valley 1.5 km south-east of Whitchurch in Hampshire and has been operated for over 50 years. The recharge area lies on a 12% slope running towards the River Test 1.7 km distant. Screened domestic sewage is distributed via a central transverse main to a system of 33 linear lagoons excavated along the contours of the slope. Each lagoon is 1-2 m deep and covers an area of about 190 m². The lagoons are used in fortnightly rotation with half the system being used whilst the remainder is mechanically desludged. Daily throughput is 0.6 Ml/d and the mean infiltration rate is 40 mm/d.

EXPERIMENTAL

Nineteen boreholes have been drilled into and down-gradient of the site (Fig.1), and cores of the Chalk have been obtained from ten of them at 1 m intervals. Groundwater samples were taken using a 300 ml sterilizable container, and by in situ samplers (6) installed in some of the boreholes. Gas samples were obtained using a hand-held vacuum pump connected to a Casagrande tensiometer sealed into the unsaturated zone. Interstitial waters have also been analysed to give profiles of chemical quality above and below the water table, but the results cannot be shown in this paper.

Chemical analysis was carried out by standard Autoanalyser techniques and by a TOC analyser. The membrane filtration procedure was used for coliform bacteria, and viruses were determined by the Thames Water Authority using the method of Slade (7). Gas analysis was by chromatography on Porapak-Q.

TRACER TEST

One lagoon was kept dry for 6 weeks and 5 l of 40% Rhodamine WT were then added during filling with sewage. Tracer was detected by pumping water from an in situ sampler at the water table in borehole 7 through a fluorimeter measuring at 590 nm.

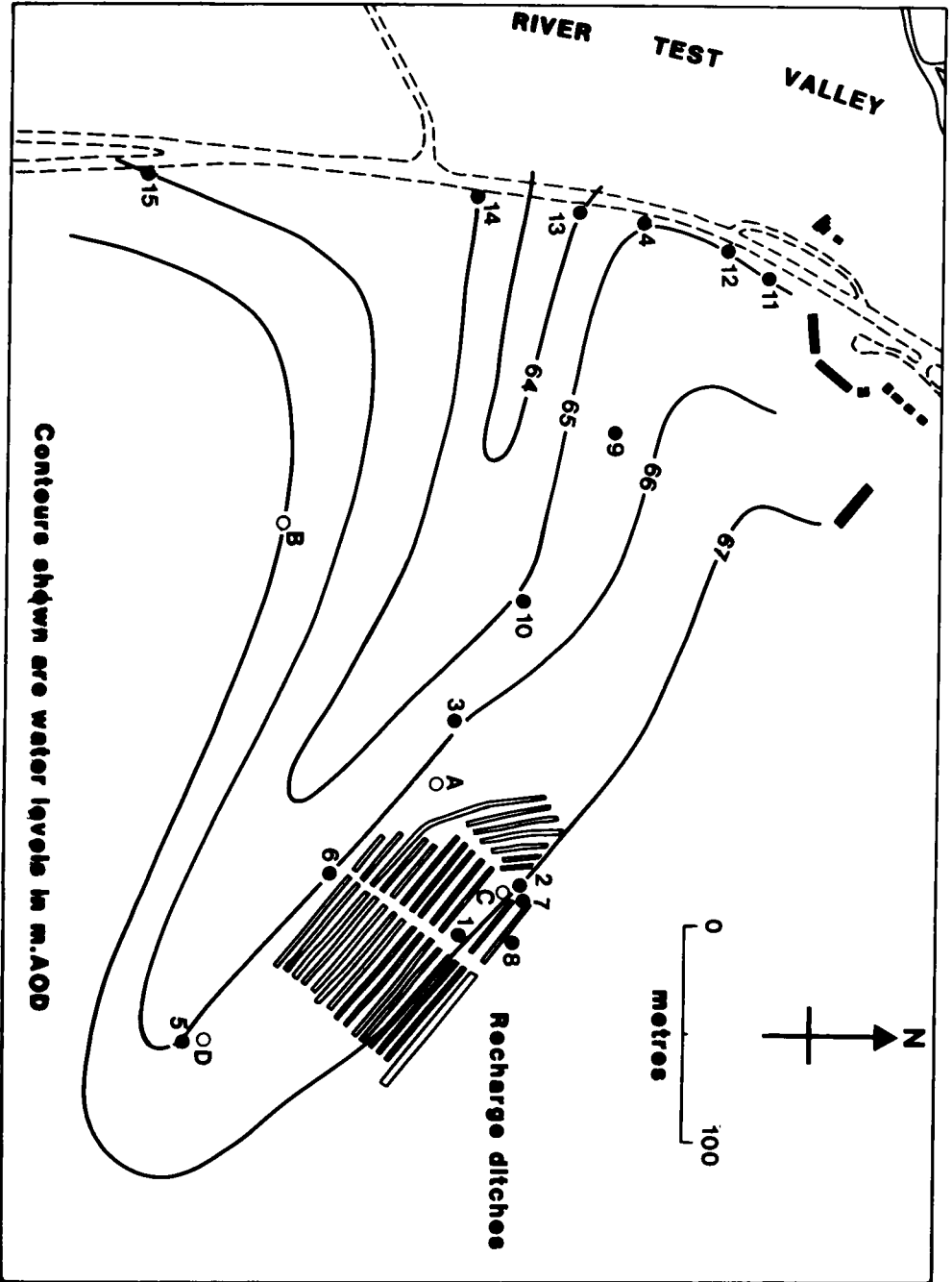


Fig.1. Whitchurch recharge area showing boreholes and groundwater contours.

NITROGEN BALANCE

In four separate exercises intensive sampling was carried out over periods up to 9h. It was established separately that mixing and retention in the sewage lagoons were sufficient to overcome diurnal and other fluctuations in sewage strength and thus provide a liquid of substantially constant composition for re-charge. Sewages were filtered before analysis in these experiments.

RESULTS

The main series of chemical results is shown as averages in Table 1. Bacteria and viruses are shown in Ref.8. Results of the four nitrogen balance experiments are given in Table 2, dilutions being calculated from comparisons of the chloride content of the raw sewage, the unpolluted groundwater, and the samples themselves.

TABLE 1

Mean values for chemical analysis of groundwater (all as mg/l)

BORE	NH ₃ (N)	TON	NO ₂ (N)	PO ₄ (P)	Cl	B	BOD (ATU)	DOC+	VOC [†]
1	15.8	3.33	0.27	6.39	46.0	0.58	30.8	7.2	0.4
2	11.5	3.86	0.088	3.69	44.3	0.53	18.8	16.8	0.8
3	17.8	1.43	0.064	3.46	45.6	0.79	5.4	24.9	2.3
6	6.4	4.76	0.053	4.26	45.6	0.93	6.8	28.0	0.9
*7	13.2	3.01	0.14	4.20	41.9	0.45	9.3	4.4	0.6
*8	22.6	0.15	0.03	1.29	51.4	0.75	15.0		
*A(bottom)	0.012	6.31	0.005	0.058	13.7	0.035	1.1	3.4	0.04
*A(middle)	0.012	6.30	0.004	0.037	12.3	0.047	1.3	2.7	0.09
*A(top)	14.8	0.18	0.005	0.980	46.8	0.74	5.6	4.7	9.7
*10	0.044	6.54	0.018	0.037	15.7	0.11	2.9	6.2	0.02
11	0.018	7.29	0.003	0.030	14.2	0.04	1.8	1.7	0.007
12	0.015	7.01	0.004	0.048	13.3	0.04	1.3	1.5	0.004
4	0.031	6.30	0.007	0.046	12.3	0.04	1.1	2.6	0.009
13	0.021	8.55	0.004	0.033	15.0	0.04	1.5	1.7	0.004
14	0.349	9.60	0.031	0.054	27.7	0.24	1.1	1.9	0.005
15	0.017	7.45	0.003	0.029	16.6	0.04	1.3	1.4	0.004
16	0.011	7.87	0.005	0.017	12.4	0.04	1.1	2.2	0.15
5	0.018	7.42	0.006	0.038	13.4	0.03	2.3		
*B(bottom)	0.009	6.89	0.004	0.033	14.7	0.03	1.3	2.2	0.8
*B(top)	0.009	8.29	0.004	0.020	19.2	0.04	1.8	1.7	0.02
SEWAGE	22.2	0.65	0.31	7.38	57.2	2.10	221	66.8	

*using in situ samplers

+Dissolved carbon after stripping of VOC

† Volatile organic carbon removed by N₂ stripping

TABLE 2
Results of nitrogen balance experiments

No.	LAGOON			BORE 2			Dilution %Effluent	N Predicted mg/l	N Lost %
	TDN* (mg/l)	TOC (mg/l)	t°C	TDN* (mg/l)	TOC (mg/l)	t°C			
1	32.9	37.4	15	19.9	16.0	12.5	85	29.0	31
2	36.4		16	19.7		12.5	95	34.8	43
3	29.1	49.8	14.5	19.7	19.7	14.0	88	26.4	26
4	70.7	39.0	9.5	35.0	22.0	13.0	80	57.9	39

* total dissolved nitrogen = TON (total oxidised N) + Kjeldahl N

DISCUSSION

The results indicate a narrow pollution plume extending in a westerly direction from the recharge site, largely confined to the zone between boreholes 13 and 15. The low values of BOD, DOC, and phosphate are noteworthy and it is only the concentrations of ammonia, total oxidised nitrogen, and boron which reveal the presence of sewage. It may be calculated that most of the ammonia has either been nitrified or removed altogether within 300 m of the recharge site. The nitrogen removal in the unsaturated zone (Table 2) is similar to that observed by other workers(9). The most likely explanation seems to be that the coexistence of aerobic and anaerobic zones (confirmed by the detection of up to 1% of methane in many of the gas samples) allows both nitrification and denitrification to take place, with the organic matter in the sewage acting as the oxygen acceptor for denitrification.

The tracer test gave a median time of descent of 18 h to the water table. Attempts to measure the horizontal flow rate were unsuccessful.

Interpretation of the results for the interstitial waters shows the depth of the plume to extend to not more than 30 m (i.e. 20 m below the water table) at the recharge site, rising to shallower depths in a down-gradient direction.

At Whitchurch and other sites under investigation processes operating in the aquifer and especially in the unsaturated zone have been found to effect a considerable degree of treatment on the applied effluents, particularly for nitrogen, phosphorus, microbes and soluble organic matter. At Whitchurch, denitrification has been found to be particularly marked with losses of N in the effluent estimated to be up to 43%. This is believed to be due to the high dissolved organic content, not present in biologically treated sewage.

At Whitchurch pathogenic bacteria and viruses are substantially removed during infiltration (8), in agreement with results obtained by Beard and Montgomery (3) for coliforms at another site. Where microbes reach the water table it appears

that lateral movement is relatively small and movement outside the boundary of the site does not occur. Starting from dry lagoon conditions, breakthrough of viruses and other microbes occurred at the same time as that of dye tracer. Thereafter, faecal streptococci and viruses, though greatly reduced by infiltration, varied in phase. Preliminary results on the changes in organic compound concentrations using TOC indicate considerable reductions after infiltration.

Though our understanding of the extent of the natural treatment processes available has been substantially advanced by the work carried out at Whitchurch and elsewhere, it is still not possible to establish widely applicable guidelines. However, an unsaturated zone of 20 m or more (i.e. twice that available at Whitchurch) appears to be a practical minimum to avoid rapid microbial breakthrough.

The Chalk must always be regarded as unreliable however because of its fissured nature and effluent recharge should never be contemplated without thorough site investigation and adequate permanent monitoring. An understanding of groundwater conditions at a site can be achieved using methods developed during this research, and the cost of monitoring systems for groundwater management kept to a minimum.

A guide to the appropriate level of expenditure for site investigation and monitoring should be deduced in the light of the cost of alternative strategies of either treatment and discharge to a river or piping sewage out of the catchment. Such costs will also reflect the value of the resource to be protected and conserved. Use of the groundwater system should not be regarded as an option which can be done 'on the cheap'.

Despite its apparent crudity the recharge system at Whitchurch appears to have no adverse effects on groundwater quality of any significance for public health or the environment. There is a positive benefit in that there is less tendency for nitrate to accumulate than when biologically treated effluents are recharged.

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REFERENCES

- 1 Tahal, Ltd. Advanced Treatment, Groundwater Recharge and Re-use of Municipal Water. Dan Region and Winter Operation. Report for Mekerot Water Co. (March 1977).
- 2 R.L.H.Satchell and K.J.Edworthy, The Trent Research Programme, Vol.7. Artificial Recharge : Bunter Sandstone. Water Resources Board, Reading, 1972 (published by Her Majesty's Stationery Office).
- 3 M.J.Beard and H.A.C.Montgomery, Wat.Pollut.Control, 80(1981) 34-41.
- 4 K.J.Edworthy, W.B.Wilkinson and C.P.Young, Prog.Wat.Technol. 10(1978) 479-493.
- 5 K.M.Baxter and K.J.Edworthy, Impact of Sewage Effluent Recharge on Groundwater in an Area in S.E.England, Proc.Int.Symp. Artificial Recharge, Dortmund, May 1979.
- 6 K.J.Edworthy and K.M.Baxter, Virology of Wastewater Recharge of the Chalk Aquifer Part I - Hydrogeology and Sampling, Proc.Int.Symp. Viruses in Wastewater Treatment, Guildford, September 1980.
- 7 J.S.Slade, J.Inst.Wat.Eng.Sci., 32(1978) 530-6.
- 8 J.S.Slade and K.J.Edworthy, Virology of Wastewater Recharge of the Chalk Aquifer Part II - Microbiology and Water Quality, Proc.Int.Symp. Viruses in Wastewater Treatment, Guildford, September 1980.
- 9 J.C.Lance, J.Wat.Pollut.Contr. Fed. 44 (1972) 1352-1361.