

THE NEED FOR AN INTEGRATED APPROACH TO WATER-SUPPLY  
AND SANITATION IN DEVELOPING COUNTRIES

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Prevention from Low-Cost Sanitation

ABSTRACT

During the coming decade much greater emphasis will be placed in developing countries on groundwater exploitation for drinking water-supplies and on unsewered sanitation. In certain hydrogeological conditions these low cost technologies may be in conflict and an integrated approach is required to avoid new pollution hazards. This paper briefly reviews the factors influencing the survival and migration of faecal bacteria and viruses in groundwater systems, assesses the threat of chemical pollution, and identifies the critical factors in the evaluation of groundwater pollution risk.

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INTRODUCTION

The period 1981-90 has been adopted by the UN General Assembly as the International Drinking Water Supply and Sanitation Decade. The goal of this decade is that all people should have access to an adequate water-supply and a satisfactory means of excreta disposal in order to reduce the incidence of water and excreta related diseases. Groundwater is widely used, and will be increasingly developed, since it is normally the cheapest and safest source of untreated potable water in developing countries. It has also been established that unsewered (on-site) sanitation can provide adequate service levels for excreta disposal at substantially less cost than mains sewerage systems (ref. 1).

CLASSICAL RESEARCH ON UNSEWERED SANITATION

The natural soil profile has long been recognised as an effective system for wastewater disposal. The detailed studies of some early researchers (refs. 2 - 4)

are directly relevant because they relate to broadly comparable excreta disposal units (latrines). Most investigations were restricted to situations where excreta were discharged directly into the saturated zone (fig. 1); lateral migration of faecal bacteria did not generally exceed 10 m in the groundwater flow direction, although a broader plume of chemical contamination could be detected over much larger distances. The extent of bacteriological pollution was observed to reduce with time, concomitant with the formation of a crust on latrine walls as a result of pore clogging. In unsaturated soils faecal bacteria were rarely found to penetrate more than 1.0 m below a latrine. These results suggested 15 m as the safe lateral separation between groundwater supply installations and excreta disposal units; a guideline which has been very widely adopted by public-health engineers. A serious limitation of the studies, however, is that they sampled restricted ground conditions; essentially sandy formations with mean grain sizes and saturated groundwater flow velocities of less than 300  $\mu\text{m}$  and 1.0 m/d respectively.

Not all hydrogeological environments are equally effective for effluent purification. Under certain conditions, in unconfined (water-table) aquifers, latrines may represent a serious pollution risk to groundwater, and thus to neighbouring water-supply installations, such as boreholes, wells and springs, and sometimes also to water reticulation mains subject to intermittent depressurisation. On the other hand, if aquifers are essentially confined or semi-confined (fig. 1), or where thick unsaturated zones of unconsolidated strata are present above unconfined aquifers (fig. 1), a 15 m separation may be too conservative. For various social reasons the minimum practicable separation will often be desired. This paper constitutes the synopsis of a major desk study on the subject, interpreted in the light of field experience (ref. 5).

## MICROBIAL MIGRATION IN GROUNDWATER SYSTEMS

### Role of soil-unsaturated zone in effluent purification

It is considered that infiltration into, and through, the unsaturated zone affords the first line, and by far the most important line, of defence against pollution for underlying aquifers from which groundwater supplies may be drawn. The performance of most latrines depends primarily on the ability of the soils and rocks of the unsaturated zone to accept and to purify sewage effluent: functions which may be in conflict and relate, either directly or indirectly, to the hydraulic characteristics.

The unsaturated zone contains continuously varying proportions of water and air; the moisture content and the unsaturated vertical hydraulic conductivity being a function of the prevailing moisture potential or tension (fig. 2). Some sands and sandstones have relatively large pores which drain abruptly at quite low tensions, in contrast to clays and siltstones whose water is strongly

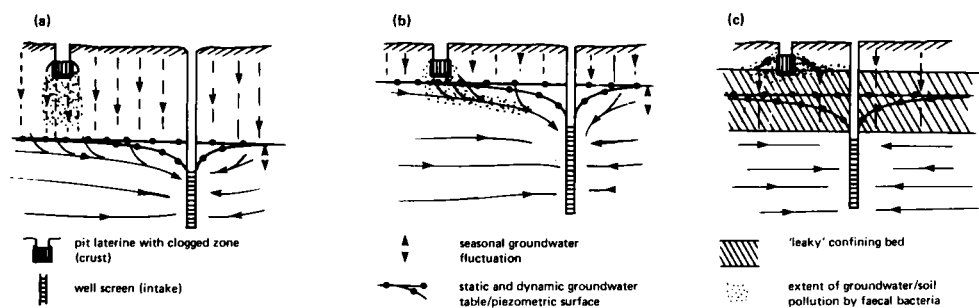


Fig. 1. Sketch sections illustrating typical pollution regimes: unconfined aquifer with (a) deep and (b) seasonally shallow groundwater table and (c) semi-confined aquifer.

retained in very fine pores. Most consolidated rocks, and some clays, contain sub-planar voids (normally known as fissures), which will also only contain (and conduct) water at very low tensions (fig. 2). In consequence, unsaturated vertical hydraulic conductivity often decreases dramatically with reduction in moisture content and groundwater flow rates in the unsaturated zone do not normally average more than 0.3 m/d. However, under conditions of heavy artificial hydraulic loading or of high intensity infiltrating rainfall, in fissured formation, they may be much higher.

When latrine effluent enters the unsaturated zone, pore clogging develops at the infiltration surface as a result of (a) changes in soil structure caused by cation exchange and swelling of clay minerals, (b) blockage of soil pores with filtered solids, (c) deposition of slimes through bacterial activity and (d) precipitation of insoluble metal sulphides, deoxygenated conditions developing after ponding has become established (ref. 6). Although pore clogging may result in the failure of some latrines, due to surfacing of effluent, the crust performs important roles: (a) it acts as a very effective filtration (straining) medium for faecal bacteria (size 0.5 - 5.0  $\mu\text{m}$ ), which are eliminated by antagonistic anaerobes, and (b) by reducing the effective infiltration rate per unit area it ensures that the moisture potential, in the unsaturated zone below, remains relatively high, thereby greatly reducing its vertical hydraulic conductivity, increasing its groundwater residence time and minimising the possibility of preferred (rapid) flow in aggregated clay soils and fissured rocks.

Passage through the crust results in the elimination of a very large proportion of the faecal bacteria in latrine effluent, but populations are so high (probably  $10^9/100$  ml) that significant numbers still enter the unsaturated zone. Surface adsorption on mineral surfaces, with degradation by other (aerobic) bacteria, is believed to be the predominant elimination process here and is

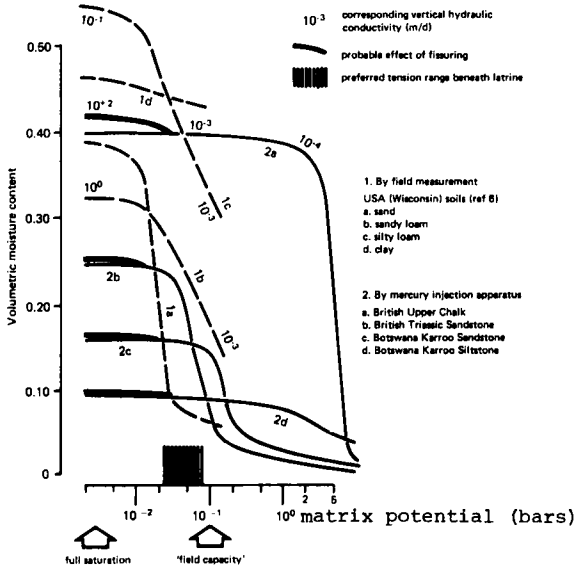


Fig. 2. Moisture content as a function of matrix potential (tension).

enhanced when liquid movement occurs only in the smaller pores of the soil/rock with maximum media-liquid contact.

Prediction of the survival time of faecal bacteria in subsurface environments is complicated by the many controlling factors: moisture content, temperature, acidity, together with organic/nutrient levels and antagonistic microbial populations. In soils, faecal coliforms generally survive less than 60 days, with  $t_{90}$  (time for 90% population reduction) normally less than 15 days, but under cool, moist, alkaline conditions a hardy residual fraction may survive for many months. In groundwater, exceptional survivals of over 100 days have been reported, but bacterial half-life in well and laboratory groundwaters is mainly in the range 0.3 - 1.0 d, that is  $t_{99}$  less than 11 days (ref.7 ).

Viruses (0.01 - 0.1  $\mu\text{m}$  diameter) are the smallest excreted pathogens and differ fundamentally from bacteria in that (a) they consist of inert particles (of ribonucleic acid) that cannot replicate outside a living host, (b) their infective dose may be orders of magnitude less, and (c) they are too small to be removed by porous medium filtration. Retardation of virus penetration into the sub-surface is thus dependent almost entirely on adsorption (ref. 8), the rate of which will vary with viral strain but increases with soil acidity. The factors controlling subsequent elimination are not well understood but degradation by aerobic bacteria is probably the dominant process. Longest survivals are likely in anaerobic, low temperature, environments, and  $t_{99.9}$  of 2 - 100

days are reported. Viruses can become desorbed from soils, especially following heavy rainfall. It is also important to note that viruses may sometimes be isolated from samples containing no detectable faecal bacteria indicator organisms, especially in anaerobic environments.

Most of the reported incidences of microbiological contamination of groundwater, resulting from the use of unsewered sanitation, are associated with areas of thin soil cover (less than 3 m) over fissured non-porous bedrock or areas of high (less than 3 m depth), or seasonally high, groundwater table.

#### Attenuation and dilution in saturated zone

Since in most hydrogeological conditions (other than close to pumping boreholes in relatively low transmissivity aquifers) the hydraulic gradient is very shallow, it might be expected that groundwater flow velocities in the saturated zone would invariably be small (less than, say, 2 m/d) and that protection of water-supply installations in unconfined aquifers against pollution from excreta disposal units could readily be obtained by increasing their lateral separation.

However, the processes responsible for the fixation of excreted pathogens (primarily adsorption) will, in most cases, be much less active than in the unsaturated zone, and the population of aerobic bacteria to affect their eventual elimination will be greatly reduced. Moreover, few aquifers are, in practice, uniform. Permeability heterogeneity will often be present, sometimes on a gross scale as in some stratified alluvial sequences and in many limestones. The presence of highly-permeable groundwater flowpaths of relatively small cross-sectional area results in groundwater velocities often exceeding 10 m/d, reaching 100 m/d or more in many fissured aquifers and 1 km/d or more in some karstic limestones. Physical (hydraulic) dispersion, the phenomenon primarily responsible for dilution of pollutants in groundwater flow systems, is also difficult to predict and costly to investigate. Thus, in many hydrogeological environments, increasing lateral separation is not a very manageable method of increasing protection against faecal groundwater pollution. Even where reliable, it must be recognised that the separation will have to be increased in large increments, say, to 25 or 50 m, and this will only be feasible in low density settlements (substantially less than about 100 people/ha).

A striking feature of the published work on lateral microbial pollution travel in the saturated zone is that migration is governed predominantly by groundwater flow velocity; appearing to be equivalent to the flow distance during a period of no more than 10 days. This implied (or apparent) survival time is much less than many reported experimental survivals, but the latter probably refer to higher initial populations, less dispersion and less antagonistic environments. The largest recorded distance of microbial travel in unconsolidated (non-fissured)

strata is 920 m, for bacterial and viral tracers in colluvial gravels (ref. 10).

#### NITRATE POLLUTION PROBLEM

The introduction of unsewered sanitation schemes will, almost inevitably, lead to nitrate contamination in underlying unconfined aquifers, except where the groundwater system is naturally anaerobic. Human waste contains about 5 kgN/cap/a, in the form of ammonium and complex organic compounds, both of which can be expected to be rapidly converted to (highly mobile) nitrate under aerobic conditions. Heavy nitrate pollution can be expected in some cases (eg.ref. 9). The factors controlling its severity will be (a) population density, (b) the proportion of nitrogen lost from the latrine directly by denitrification, (c) dilution by local groundwater recharge and regional aquifer throughflow, (d) any denitrification in the groundwater system itself.

#### CONCLUDING REMARKS

In view of the complexity of the factors involved, and the potential importance of rather detailed considerations, it would be desirable to treat each settlement or site on individual merit when assessing the faecal pollution risk associated with unsewered sanitation. However, the economics and logistics of low cost sanitation schemes are such as to preclude the routine use of hydro-geological field investigations and, in practice, a classification of hydro-geological environments is required as the basis for new guidelines.

The classification must identify under which conditions a separation of 15 m between water-supply installation and excreta disposal unit (a) can be reduced to 10 m, or even 5 m, (b) is acceptable, (c) may involve significant risk and increasing separation to 25 or 50 m accompanied by monitoring of pilot schemes is advisable, and (d) involves high risk and specialist advice should be sought, since modified excreta disposal units or redesign/relocation of water-supply installations may be required. It must be workable with data readily available to public-health engineers from records normally held locally in government offices/agencies, or that they can collect on site following a simple manual. The principal parameters involved have been identified as (a) degree of confinement and character of the aquifer horizons from which groundwater supplies are drawn, (b) thickness and nature of the unsaturated zone, and (c) latrine hydraulic loading.

A preliminary classification in the form of an algorithm has been drawn up using these parameters (ref. 5) but further data are required for its consolidation and extension. Such data could best be collected by detailed field research and/or routine monitoring associated with pilot on-site sanitation schemes.

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