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ON-SITE SANITATION AND GROUNDWATER QUALITY : A METHODOLOGY FOR MONITORING

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1981

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ABBREVIATIONS

km	kilometres
l/s	litres per second
m	metres
ml	millilitres
mm	millimetres
m/d	metres per day
mg/l	milligrams per litre

I

INTRODUCTION

A. Scope and purpose of this report

This report recommends a methodology for establishing a basic, but meaningful, groundwater quality monitoring programme in areas where on-site excreta and sullage[1/] disposal systems are installed or where their feasibility is being considered. Such a monitoring programme may on the one hand enable assessment of the potential pollution hazard and on the other enable any changes in groundwater quality subsequent to the installation of on-site disposal systems to be adequately monitored.

The problem of risk appraisal is discussed at length in a companion report (Lewis et al., in press) which describes the processes leading to pollution in various hydrogeological environments and the scientific reasoning is not repeated herein. The aim of the present report is rather to enable a basic monitoring programme to be established without necessarily utilizing specialist hydrogeologists and public health engineers. The report is therefore directed at non-specialists, that is those without previous or detailed knowledge or field experience in geology, hydrogeology, hydrochemistry or microbiology. Technical jargon is therefore kept to a minimum: technical terms which are underlined where they first appear in the text are defined in the glossary (Annex 1).

The recommendations of this report are the minimum required for a meaningful groundwater quality monitoring programme. It is recognised that more sophisticated programmes are possible and indeed IRCWD[2/] is recommending

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1/ Defined in Annex 1
2/ The WHO International Reference Centre for Wastes Disposal, Dübendorf, Switzerland.

more detailed field studies in specific localities. However, in most developing countries financial and manpower constraints preclude a more sophisticated approach. The methodology outlined here can and should be followed even where these resources are scarce. The importance of a complementary monitoring programme where on-site sanitation and water supply wells and boreholes exist side by side cannot be overemphasised. An effective monitoring programme inevitably involves some expense and efficiency and accuracy should not be sacrificed in favour of cheapness; misleading data may be worse than no data.

As far as possible therefore, the methods recommended for the construction and operation of a monitoring programme and for the analysis of groundwater samples utilize robust and reliable equipment, materials which are normally easily obtainable and the minimum of specialist knowledge and skills. Certain techniques have been dismissed as being too simple to provide meaningful information. Other techniques have been omitted as being too sophisticated in either the monitoring phase or in their interpretation to warrant inclusion in this report. In particular, groundwater sampling in the unsaturated zone, pumping tests, tracer tests and geophysical techniques are not recommended in this context because they involve specialised equipment and interpretation. Where a specific problem is encountered, or sub-surface conditions are unusually complicated, these techniques may usefully be applied under the guidance of specialists. The recommended field and laboratory analytical techniques have been selected because they are generally less demanding in terms of cost, time and skill whilst still giving tolerably accurate results.

Where there exist the necessary facilities (perhaps at a hospital), more sophisticated techniques of analysis may be used to advantage.

B. <u>Limitations in the application of this report</u>

The recommendations of this report may not be appropriate in all hydrogeological situations. For example, where fissuring or soil structure plays a major role in controlling the rate and direction of groundwater flow, and hence the spread of pollution, the generalisations inherent in a report of this nature break down. All groundwater related problems are to some degree site-specific since the detailed character of <u>soils</u> and <u>bedrock</u> varies from one point to another. Nevertheless the proposed guidelines for a monitoring scheme are widely applicable.

The findings of Lewis et al. (in press) indicate that the pollution problem will normally be limited to <u>unconfined aquifers</u>. Where groundwater <u>recharge</u> is impeded by a semi-confining or confining layer (with low <u>permeability</u>) on-site sanitation schemes do not present a pollution hazard, that is provided boreholes are properly constructed so that they do not act as conduits of pollution to the <u>confined aquifer</u>. Confined aquifers are therefore not specifically considered in this report. In the field the degree of aquifer confinement may not be readily apparent: the procedure outlined in this report should be adopted unless there is adequate evidence of confined conditions.

C. Factors effecting the pollution of groundwater by on-site sanitation systems

Lewis et al. (in press) have reviewed the literature and described the factors which appear to determine the degree of groundwater pollution arising from on-site sanitation systems. Their main findings are summarized below and provide a basis for the recommendations of this report. Figure 1.1 illustrates the hydrogeological factors determining the risk of groundwater pollution.

(i) The unsaturated zone, above the permanent water table affords the most important line of defence against the pollution of underlying aquifers. The nature of the materials and the thickness of this zone are key factors in determining pollution risk.

(ii) Soil (unconsolidated material) provides a very effective natural treatment system, having the ability to remove faecal micro-organisms and to break down or attenuate many chemical compounds.

(iii) The key factor in reducing microbiological pollution of groundwater is the maximisation of effluent residence time in the unsaturated zone. The natural treatment processes, such as filtration, are more efficient in fine grained, unstructured soils: structures such as root channels, animal burrows, natural voids and fissures commonly lead to short-circuiting of the natural treatment system, a consequent reduction in residence time in the unsaturated

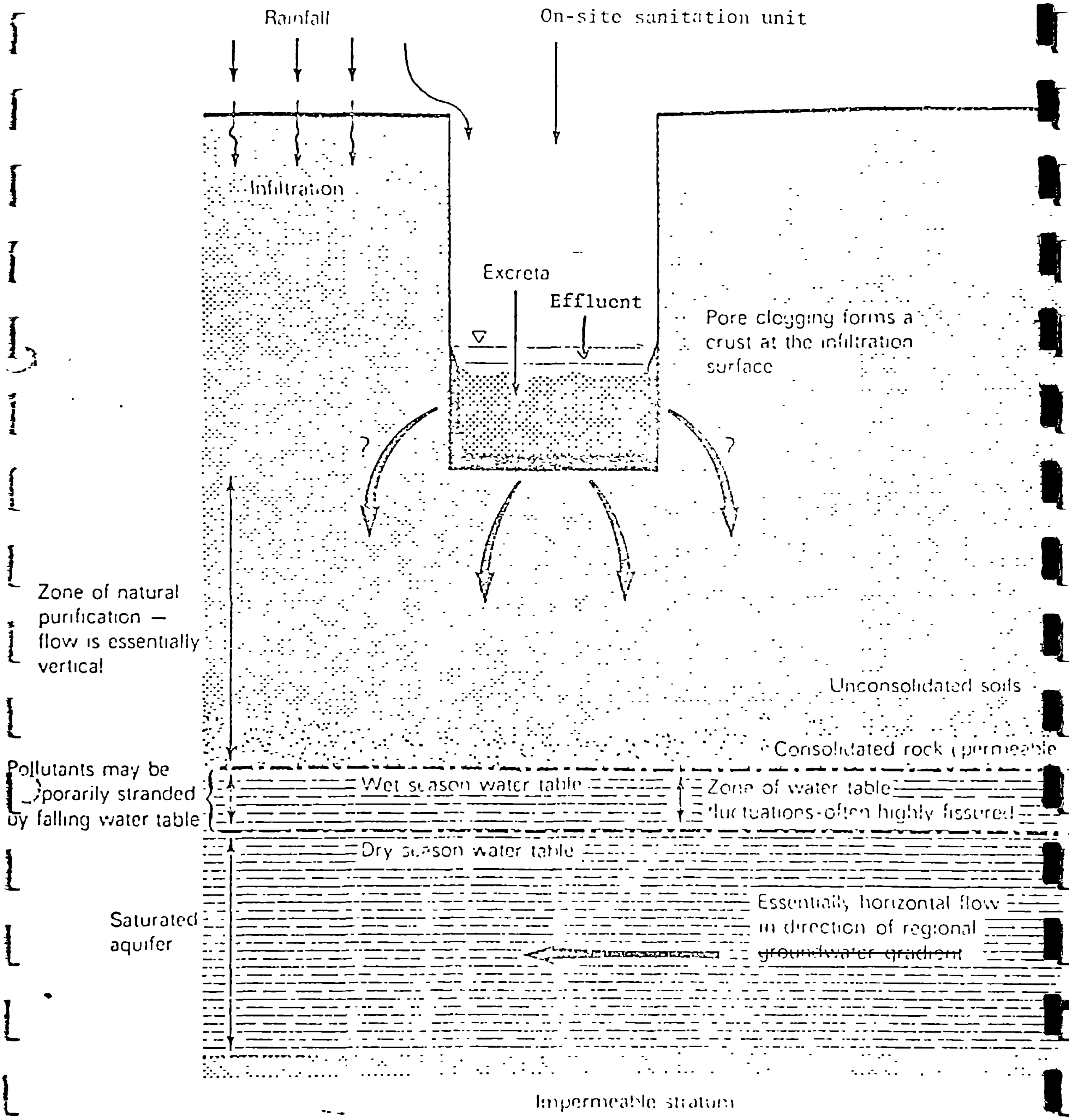


FIGURE 1.1 : Sketch to illustrate the hydrogeological factors determining the risk of groundwater pollution from on-site sanitation

zone and a greater risk of groundwater pollution.

(iv) Clogging of the infiltration surface in the latrine pit enhances bacteria and virus removal processes so that the risk of pollution diminishes after the first 100 days or so of pit usage.

(v) More specifically, the risk of groundwater pollution will be minimal where more than 2 m of fine unsaturated soils are present beneath the latrine pit, provided the hydraulic loading does not exceed 50 mm/d.

(vi) In the saturated zone pollutants move with the groundwater causing a pollution plume to develop from the pollution source. Microbiological pollutants are not normally found beyond the distance travelled by groundwater in around 10 days.

(vii) The extensive use of on-site sanitation systems almost inevitably leads to increased nitrate levels in underlying aquifers. Once nitrates enter the groundwater body they may remain there a very long time.

As a result of the literature study Lewis et al. (in press) drew the following conclusions.

(i) The risk of groundwater pollution is a function of the conditions prevailing at the site; these include the local hydrogeology and the design and operational details of water supply and sanitation installations.

(ii) A system of classifying hydrogeological environments in relation to pollution risk is a pre-requisite for adequate planning and appraisal of on-site sanitation schemes.

(iii) Groundwater quality monitoring is an essential component of pilot on-site sanitation schemes.

II

SELECTION AND ANALYSIS OF THE PROJECT AREA

A. Selection of the "project area"

Due to the costs involved in establishing and operating a monitoring network it is not feasible to monitor the effects of all on-site sanitation installations. Rather the monitoring network should be concentrated in a relatively small area, selected as the project area, where site conditions can be established in detail.

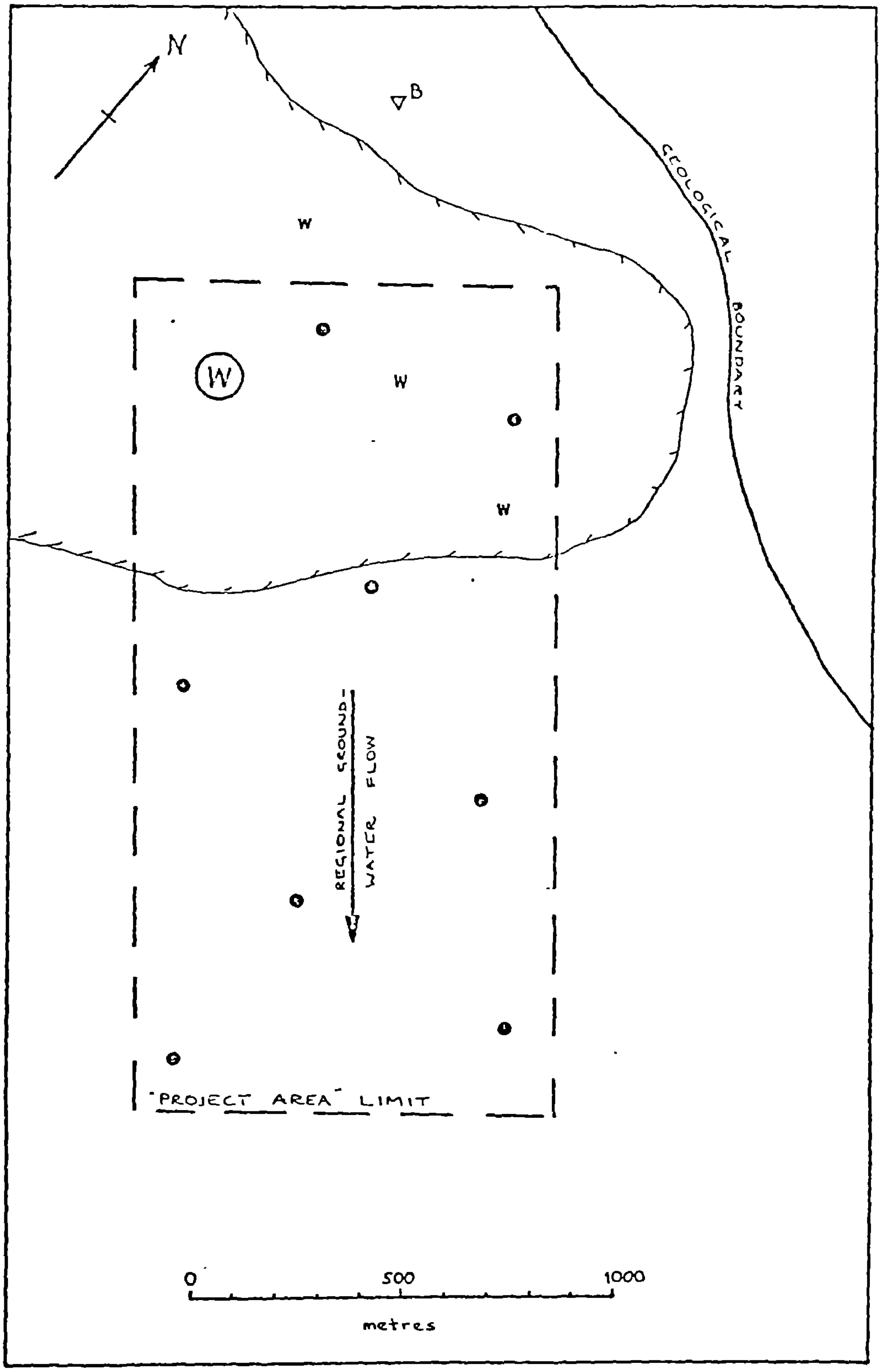
The boundary of the project area is not important and observations, although concentrated there, will not necessarily be confined to that area; to establish background conditions, for example, it may be necessary to site observation and sampling boreholes outside the designated project area. It is difficult to give firm recommendations regarding the size and shape of the project area as site conditions vary considerably. However it should usually be an area of at least 2 km^2, say, a rectangular area 2 km (in the direction of regional groundwater flow) x 1 km: see for example Figure 2.1.

The project area should be chosen with care and should be representative of the wider region so that the results of the monitoring programme can be extrapolated. Selection of a suitable area should be based on the following criteria:

(i) The project area should as far as possible be typical of the larger region in terms of geology, soils and land use.

(ii) Priority should be given to areas which already have potential

FIGURE 2.1: THE PROJECT AREA



SETTLEMENT LIMIT

(W) PUMPED GROUNDWATER SOURCE POSSIBLY CAUSING SHORT TERM FLUCTUATIONS IN GROUNDWATER LEVELS.

o OBSERVATION BOREHOLE

W SMALL GROUNDWATER SOURCE

▽B SAMPLING SITE TO ESTABLISH BACKGROUND WATER QUALITY [illegible] widespread utilisation of groundwater.

(iii) If relevant information is already available for a particular area, then there will normally be a considerable saving in time and resources if this area is selected as (or included in) the project area.

(iv) The project area should be easily accessible and, ideally, sites readily available for <u>observation boreholes</u> and sampling installations. The proximity of laboratory facilities for the analysis of groundwater samples may also be a significant factor.

The design of the monitoring network within the project area is discussed in Section III.

B. <u>Site investigation</u>

Site investigation should produce detailed information about:

(i) the local hydrogeology (including groundwater quality),

(ii) existing and proposed sanitation and drainage facilities,

(iii) existing and proposed water supply facilities.

Lewis et al. (in press) make it clear that pollution risk is closely governed by local hydrogeology; of particular significance are the nature of the unsaturated zone and the degree of consolidation of materials beneath the disposal unit (see Section I-C). The significance of water quality observations can only be interpreted against a knowledge of the background conditions prevailing in the area: it is essential therefore to monitor water quality either before the installation of on-site sanitation systems or upstream of the project area. Periodic analyses of water samples from these "background" sources should be carried out in order to check that any observed changes in water quality in the project area are a result of changes in sanitation levels in that area.

The sanitation disposal units dictate the potential pollution risk and detailed information about their design, installation, location and usage is a necessary component of site appraisal. Other sources of pollution may confuse the issue and the project area should be examined with a view to locating and evaluating any such sources.

The extent to which groundwater is used as a resource determines the need for groundwater quality monitoring and influences the design of the monitoring network. Where groundwater offers an attractive source of supply there is obvious cause for concern about pollution of aquifers. There is also a significant relationship between water supply and waste disposal; for example, a more accessible supply of water will usually, though not always, reuslt in more water being used per capita which in turn may result in greater hydraulic loading of the sanitation facility and thereby a greater pollution risk.

There are two phases to the site investigation. First, a desk study may reveal a considerable amount of relevant data already in existence. Maps of various types, aerial photographs and reports written in relation to other projects may be invaluable sources of information. Maps showing relief, and drainage, geology and soils will be the most useful. Government departments should be able to supply details about existing and planned water supplies and sanitation installations. The purpose of this phase is to aid the final selection of the project area, and to prepare a base map. It may also serve to arouse interest and encourage local participation in the project.

In the second phase a programme of field work in the selected project area should confirm and augment the findingsof the desk study. This will inevitably involve some capital expenditure but costs can generally be reduced by completing site investigation boreholes as part of the monitoring network 1/.

C. Field procedures for studying site hydrogeology

A recommended procedure for studying the hydrogeology of the project area is as follows:

(a) Hand or power auger shallow holes to 3 m below the base of selected disposal units. These should be closely adjacent say, within 2 m of the unit. Auger 3 or 4 holes for each latrine type and each soil type where variations are obvious.

(b) Auger or drill deeper boreholes into the aquifer. Ideally these boreholes should constitute part of the monitoring network (see Section III for details of construction and completion).

1/ See, therefore, Section III for recommendations regarding the number and location of observation boreholes.

(c) Sample and log all boreholes. The method of sampling will depend on the drilling method and the nature of the material encountered (see Annex IV). A representative sample should be collected, say, every 0.5 m and whenever a change in rock or soil is detected. The borehole log should include any information (such as drilling rate) which might help to produce a clearer picture of the aquifer and overlying materials; construction details should also be given. An example data sheet is presented in Annex V.

(d) Carry out a mechanical analysis to determine the grain size distribution of the soils, from a depth corresponding to the 3 m zone immediately beneath existing or proposed disposal units. Recommended procedures 1/ should be followed carefully.

(e) Determine the moisture content of selected samples. This together with (d) gives some measure of soil properties which does not suffer from the subjectivity of descriptive analysis. Standard practices 1/ should again be followed and particular care taken to preserve the samples by storage in air-tight containers and refrigeration.

(f) Take water level measurements during drilling and afterwards as part of the monitoring programme (see Section III). Where various water levels are observed during drilling they may be indicative of perched water tables or layered aquifers.

1/ Standard practices for site investigation procedures are set out in, for example, British Standards Institution BS 1377 and CP 2001, American ASTM Part 19, West German DIN 4021 and 4022, Australian Standards 1289 and 1726-1975 and Indian Standards 1498-1970 and 2720.

(g) Sample and analyse water from one or two sources to establish background water quality. Analysis should include at least all those constituents which are to be monitored routinely within the project area: (see Sections III and IV for details of sampling methods and analytical techniques).

D. Sanitation Data

The factors listed below each have some bearing on the size or nature of the pollution hazard and so should be noted.

(a) For each type of sanitation system:

Method of disposal: sewered, unsewered.

Type of sanitation unit: pit latrine (single or twin pit), pour flush toilet, aqua-privy, septic tank.

Dimensions: depth and capacity of pit, soakaway or drainfield.

Location: in relation to water supplies, other sanitation units, drainage systems and streams.

Use: numbers of people per unit, nature of deposited material.

Hydraulic loading: pour flush toilets, septic tanks sullage, drainage water.

(b) For the project area:

Number of disposal units of each type.

Density of disposal units.

Other disposal facilities, e.g. for stormwater.

Reticulation (if sewerage).

Demographic factors: population density, numbers per dwelling, state of health of population.

Water use and consumption pattern (see below).

Other possible pollution sources: e.g. livestock, sewerage (especially broken and leaking sewer pipes), nightsoil disposal, fertilizers, open wells, refuse tips.

E. Water supply data

The following details should be recorded for both public and private water supplies.

(a) For each abstraction unit:

Type of abstraction unit: e.g. borehole, well, spring.

Method of abstraction: e.g. pumping, gravity feed.

Discharge rate 1/: average daily discharge,
maximum discharge rate,
hours of pumping.

Water quality 2/.

Location in relation to excreta disposal units.

Design of abstraction works: including details of depth, casing, screening of boreholes; depth of pump installation, pump capacity.

State of sanitary protection.

Reticulation (if any): size and layout.

1/ This is often not recorded but can be estimated by multiplying population served by per capita water use.

2/ Efforts should be made to monitor the quality of any water source as a matter of routine.

(b) For the project area:

Number of abstraction points.

Total discharge: daily average,

daily maximum.

Locations of supply sources.

Water use and consumption: per capita consumption, sullage production.

Three general cases will exist with regard to water supply arrangements:

(i) groundwater not yet developed but offering a potential future source of potable water;

(ii) scattered water supply units that are relatively small (i.e., having an average abstraction rate of less than 5 l/s and usually less than 1 l/s); these will generally have no significant effect on the regional movement of groundwater within the aquifer. (This will be the usual service level in areas with low population densities.)

(iii) a single high yielding water supply installation, normally with reticulation, abstracting more than 5 l/s and often more than 20 l/s: an extensive cone of depression may be created in the water table around the abstraction point. (This level of service will more probably be installed where there are higher population densities.)

F. Changes in site conditions

It is obvious that when the aim is to predict water quality, it is essential to be aware of any projected changes in site conditions, such as the provision of additional water supply or sanitation facilities and any new sources of pollution.

The consequences of improved levels of service of water supply and sanitation are less easy to predict. Water usage often reflects cultural traditions and the amount used for personal hygiene for example, may not necessarily increase in proportion to availability. For this reason health education programmes are recognised as being crucial and with their support water usage should increase. The usage of sanitation installations may change with time as water consumption increases and water usage habits change as a result of the health education programmes. Improvements in the levels of basic services, such as water supply, may stimulate changes in population distribution and land use. For example, livestock are often encouraged to graze around water supplies; pathogens or other contaminants from animal excreta may be washed into the ground so that the aquifer and water supply are in danger of becoming polluted.

III

THE MONITORING NETWORK

A. The Monitoring Network

The immediate purposes of a monitoring programme are two-fold, firstly to ascertain the spatial extent of any pollution within the aquifer and secondly to monitor any changes in water quality with time. A monitoring network must therefore be established, water samples collected systematically for analysis and a complementary programme implemented for the observation of groundwater levels and rainfall.

The design of the monitoring network will depend upon the site conditions, that is on its hydrogeology and the water supply and sanitation service levels (Section II). The procedure for the construction and operation of a monitoring network is set out below. Methods are recommended for constructing observation and sampling boreholes: detailed consideration is given to their location and design. Methods of measurement and sampling and suitable frequencies for observations are suggested. Additional details of borehole design, equipment installation and other supporting information are given in Annexes II to VII.

The degree of sophistication and success of the monitoring network will also depend to a great extent on the quality of the manpower resources available for both construction and maintenance of the network. The network should be planned with this constraint in mind.

B. Rainfall Measurement

Rainfall is measured by a rain-gauge and expressed as depth in millimetres.

The use of a standard pattern rain-gauge is recommended; specifications and installation requirements are given in Annex VII. Automatic gauges are expensive and are not always reliable; their use is not recommended in the present context.

There may already be a rainfall station in or close to the project area. Where a gauge, or gauges, are found to exist they should be checked to ascertain the reliability of the data and the representativeness and the site . Rainfall does not normally change dramatically over short distances in flat terrain, except in the very short term, and so use can usually be made of a gauge up to 10 km away from the project area. However, in mountainous terrain, rainfall may vary considerably over shorter distances and the representativeness of any gauge may be questionned. Rainfall generally increases with altitude but also tends to decrease rapidly inland from the coast.

Frequency of observation

The main purpose of measuring rainfall is to correlate rainfall events with recharge and changes in groundwater levels and for this weekly cumulative totals are sufficient.

C. Groundwater level observation

Depth to water level can be measured in any well or borehole that penetrates the water table provided there is access for a measuring probe. In addition springs, seeps and marshy areas often indicate where the water table reaches the ground surface.

Existing wells and boreholes which have been constructed for water supply purposes may not be suitable for obtaining groundwater level data for two reasons: a borehole which is efficiently protected against the possibility of pollution entry may not have access for a measuring probe, and water levels in a pumped well will fluctuate as the discharge varies and will not be representative of regional groundwater levels. However, it is always cheaper to modify existing wells and boreholes than to drill new ones and so this possibility should be considered. It may be necessary to install additional observation boreholes or piezometers to obtain a full picture of the water table configuration in the project area.

Observation borehole design and construction

Groundwater levels may be observed in simple and consequently cheap boreholes or piezometers. An observation borehole has slotted casing extending through the entire saturated thickness of the aquifer and enables a general water level to be measured. A piezometer only allows entry of water from specific horizons and gives a depth specific pressure reading and will be more appropriate where perched aquifers are present and used for water supply (see Figure 3.1).

Observation boreholes must extend below the dry season water table for at least 3 m and should preferably penetrate the full depth of the aquifer (where this is less than, say, 30 m). Locally available equipment and materials should be utilised where possible. The casing and piezometer pipe may be of PVC, steel or bamboo. Narrow slots, cut with a hacksaw, allow

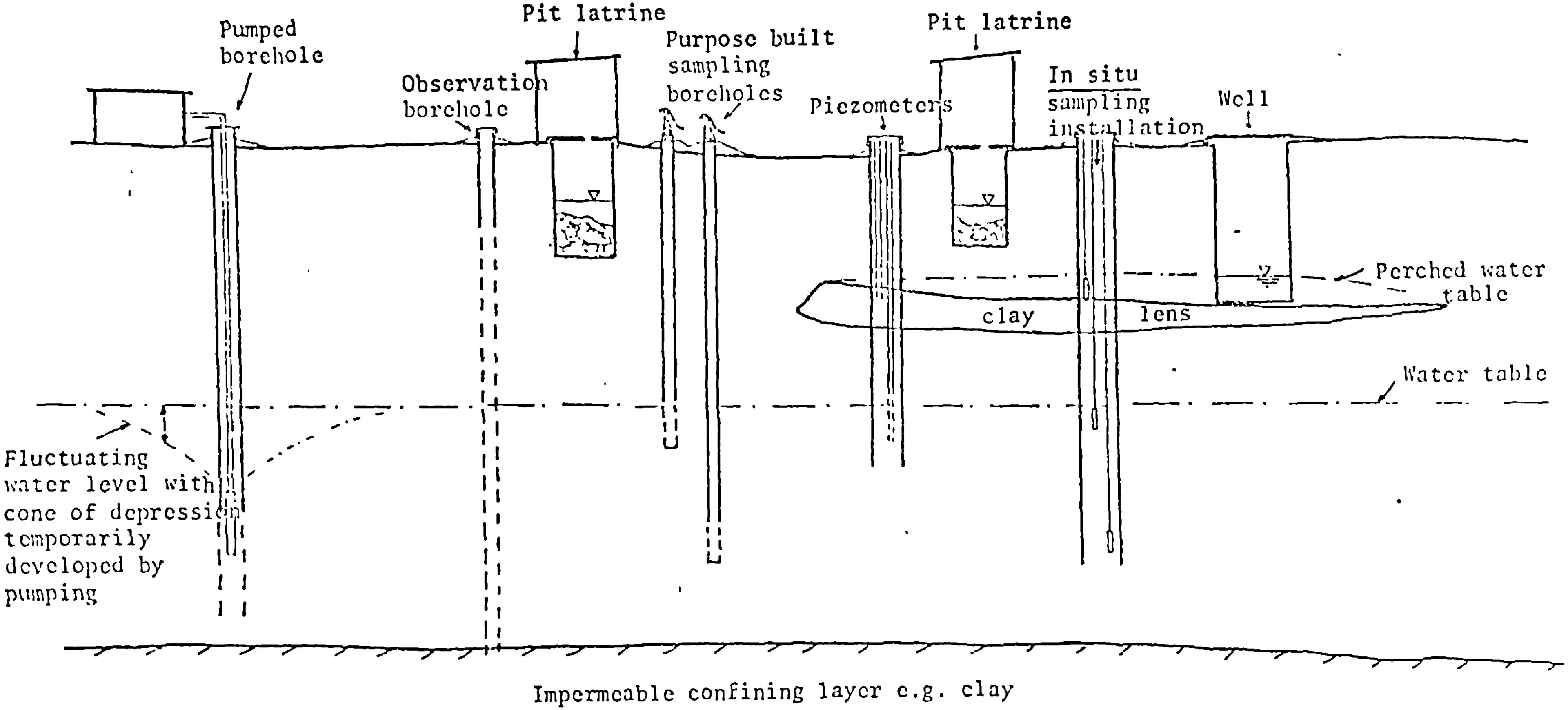


FIGURE 3.1 : Water supply, observation and sampling installations in an unconfined aquifer

entry of water whilst excluding the aquifer materials. Design details are presented in Annex II.

The method of drilling will depend on the nature of the sub-surface material. For soils or soft rock and shallow depths (<15 m) an auger or bailing method may be used, but for harder rock or deeper holes a percussion or cable-tool rig may be necessary (Annex IV). All other forms of drilling are either impractical in the present context or likely to be too expensive unless large numbers of boreholes are involved.

There is a great danger that any borehole may permit the passage of pollutants from the surface into the aquifer. Each borehole must be carefully protected against this possibility and against vandalism. The casing should protrude above the surrounding ground level by at least 300 mm and be sealed by a screwed cap (secured with a lock) which can be removed to measure the water level (or into which a small plug is fitted).

A cement grout should be inserted between the casing and the wall of the borehole to at least a depth of 3 m to effectively seal out contaminated water from the surface. The ground should be built up slightly around the borehole and concrete set in place to prevent surface run-off collecting in the vicinity of the borehole (see Annex III).

Each borehole should be levelled in (relative to a known datum) and the reference datum clearly and permanently marked so that water level measurements are meaningful. A reference number should also be clearly marked on the borehole casing.

Location of observation borehole

The number of observation boreholes required will depend on the extent of existing knowledge of the aquifer and groundwater in the project area. As a general rule 4 boreholes per km^2 should be sufficient but additional boreholes may be necessary to determine the extent of cones of depression around the larger water supply sources. The boreholes should preferably not be sited within 50 m of a pumped source so as to avoid rapid short-term fluctuations in groundwater level: see, for example, Figure 2.1.

Areas where information is insufficient to establish the water table configuration will become apparent if the data is compiled in the form of a water table map (see Section V). Additional boreholes can be drilled to fill these information gaps and the water table map updated.

Measurement of water levels

Water level measurements should be made manually. Sufficient data can be obtained by regular visits to monitoring sites and automatic water level recorders are not necessary.

Depth to water level is measured by means of a well tape. This may take the form of a chalked steel tape which is lowered some distance into the water; the depth to water table is then given by the total length minus the wetted length. Other well tapes contain conducting wires and visual or acoustic indicators which are triggered when the probe makes contact with the water. (Flashing lights are difficult to see in bright sunlight and so are not the most suitable indicators.) Several commercially produced well tapes are available 1/ .

If water level readings are required from a pumped borehole a small

1/ For example, from A.Ott, GMBH, P.O. Box 2120, Federal Republic of Germany.

diameter (25 mm) perforated tube should be installed to below the level of the pump.

Frequency of groundwater level monitoring

Water level measurements should be made weekly initially. Once the relationship between rainfall and well water levels has been established it may be sufficient to take readings on a monthly basis (Table 3.1). Measurements should be made in all the observation boreholes over as short a time as possible in order to be able to interpet the instantaneous configuration of the water table.

D. Groundwater sampling

It is important to ensure that a representative water sample is obtained. The quality of standing water in a well or borehole will not usually be representative of the groundwater within the aquifer. Certain constituents of the water will be effected by exposure to the atmosphere, light and higher temperatures and the difference in quality of water in the aquifer and that in the well may be considerable, especially in large diameter shallow wells. Meaningful samples cannot readily be obtained from open holes by simple scoop methods.

It is also important to establish the source of the sample, that is the horizon, or horizons, in the aquifer which contribute the sample. Groundwater flow in the saturated zone is predominantly horizontal and there is little vertical mixing; so it can usually be assumed that the sample is derived from that part of the aquifer adjacent to the sampling interval. Thus the part of the aquifer contributing groundwater to the well or borehole will often depend upon the design of the hole rather than the nature of the aquifer. Solid casing will exclude the entry of water from particular horizons and this can be used to advantage

Table 3.1 : Monitoring Schedule : Frequency of Observations 1/

Observation	Initially	After 3-6 months 2/	After 1 year
Rainfall	Weekly	Weekly	Weekly
Water Levels	Weekly	2-weekly	Monthly
Water sample collection and analysis	Weekly	Monthly	Monthly

1/ This table should be used as a guide when planning the monitoring and sampling programme; more suitable frequencies may become apparent as the monitoring exercise proceeds.

2/ The frequency should be reduced only where it can be stated with confidence that there is nothing to be gained from more frequent observations and site conditions remain unchanged. This is not the case at least until an entire recharge period or wet season has been monitored.

in designing a sampling borehole: (the depths of cased and screened sections should be ascertained with precision). Depth samples from open holes should be treated with caution and are only feasible when their collection is closely supervised by a trained hdyrogeologist using ancilliary techniques to establish the source of the water.

Samples should preferably originate within say, 3 m of the water table since microbial pollutants tend to be concentrated at the top of the saturated zone. Water supply boreholes are often cased to several metres below the water table and so they may not be satisfactory sample sources on their own.

Hence, samples can be collected from either pumped water supply sources 1/ or naturally flowing springs, or purpose-built sampling installations. It is unlikely that there are sufficient suitable existing boreholes to provide an adequate sampling network and so additional sampling points will have to be constructed. In this event it is recommended that depth specific samplers be installed.

(a) Pumped sources

Pumped water can only be expected to be representative of the water flowing through the aquifer when pumping has been continuous for several hours prior to sampling: ideally this would exclude the use of hand pumped boreholes for monitoring purposes. However, in practice this may often be the only viable means of collecting a sample: see, for example, (c) below.

Where a source is pumped specifically to obtain a water sample it must be remembered that the discharge will at first be mainly

1/ However, only where these are adequately protected against pollution (see Annex III) the standing water from the borehole. It may take some time before this water is cleared and the pumped discharge is totally derived from the aquifer. In this case it is useful to record the temperature of the discharged water. The standing water will usually be warmer than the water in the aquifer and so the temperature of the pumped discharge will be expected to fall with time: when the temperature steadies to a constant level a sample can be collected; this may take from a few minutes to several hours or sometimes as much as 1 day.

(Where the borehole is used for water supply it may be instructive to take samples at the start of pumping as well, as this standing water may be equally representative of the supply).

The pumped sample should not be considered as simply averaging the water quality over the penetrated depth since certain more permeable horizons may supply water preferentially to a borehole during pumping. It is difficult to establish the origin of a pumped sample, but the rate of discharge and the drawdown at the borehole may be indicative and should be recorded.

(b) Springs

Groundwater can be sampled from springs provided suitable precautions are taken to avoid contaminating the sample with soil particles and bacteria. Groundwater will be contaminated by atmospheric oxygen when it emerges from a spring; this will effect the determination of easily oxidized constituents, such as iron, and other properties such as pH.

Small springs in unconsolidated deposits can be sampled by driving a slotted pipe to a depth of about 1 m into the ground adjacent to the spring: groundwater will normally flow from the pipe. For larger springs emerging from consolidated rock it may be possible to push a heavy metal pipe into the mouth of the spring to facilitate collecting a representative sample (Wood, 1976).

(c) Depth specific sampling installations

(i) Purpose-built sampling boreholes:

Although not technically the best solution, purpose-built boreholes of various depths, each screened over a limited interval of about 1 metre, will commonly provide a viable method of collecting groundwater samples from known horizons within an aquifer (Figure 3.1). It should be possible to construct this type of sampling installation using locally available materials and skills: the method of construction is the same as for observation boreholes (see Annexes II and IV), but particular care must be taken to isolate the screened interval. Following construction each borehole must be pumped hard so as to eradicate any drilling disturbance and allow unimpeded entry of the groundwater from the aquifer.

Each borehole must be properly protected against the ingress of pollutants (Annex III) and fitted with a protected pump, which may be hand operated. The pump should be secured so that the sampling installation cannot be used for water supply purposes. However, the precautions noted for collecting pumped samples should be followed when sampling from these installations.

For shallow aquifers (less than 10 m) a suction pump may be used to raise the samples. This is a cheap alternative and permits use of small diameter holes ($\leq$ 50 mm) which may perhaps be driven in at low cost. For deeper aquifers more sophisticated pumps and consequently larger diameter boreholes ($\geq$ 100 mm) are necessary.

It is most important to sample from the vicinity of the water table and so in the majority of boreholes the screened length should occupy the top of the saturated zone. Other boreholes should be screened at various depths below the water table to give an indication of any variation in water quality with depth. If a particular horizon is known to make a major contribution to the flow into the borehole (which may become evident during borehole construction) then the open or screened intake section should be placed at that level.

Since water levels can be expected to respond to variations in recharge rate and hence fluctuate seasonally it is not possible with fixed sampling positions always to sample from the same depth below water table. Unless the screened interval extends below the dry season water table there will be part of the year when samples are unobtainable; it is likely that the minimum water level is unknown and so there may inevitably be gaps in the sampling record at some localities.

(ii) <u>In situ samplers</u>:

A number of depth specific, *in situ* sampling devices have been developed details of which are given in Annex VI. For use in the present context (for monitoring chemical and microbiological groundwater quality in developing countries) any sampling device needs to be simple, bacterially and chemically inert, reliable and rugged in operation, yet inexpensive. Unfortunately, these *in situ* systems have yet to be thoroughly tested under the range of conditions which may be experienced in the field in less developed, and, for example, the supply of gas to operate the sampler may prove difficult. In remote areas it may be impracticable to rely on imported products which anyway are inherently expensive. A further uncertainty regarding the sampling devices produced so far is their suitability for microbiological sampling: ceramic and some plastic materials are bacterially active and stainless steel is prohibitively expensive.

However, the inherent advantages of permanently installed sampling systems make them an attractive option for long-term groundwater quality monitoring 1/.

1/ There are several recent reports (see Annex VI) of prototype sampling systems which are now (1981) undergoing field tests. It may not be long before their use can be recommended with greater confidence.

Provided the sampler is correctly installed (and this requires a careful, experienced and conscientious work force) the part of the aquifer contributing to the sample is known. It is recommended that normally two samplers should be installed in each borehole, one near the top of the saturated zone and one some 5 - 10 m below this level. If the aquifer is thick or a particular horizon is known to make a major contribution to the flow into the borehole then it may be useful to install a third sampler: see for example Figure 3.1. The effective length of each sampler (see Figure VI.1) should be approximately 1 m with the intake area set centrally. It is extremely important to isolate each sampling length effectively with impermeable seals.

The same limitations with regard to the relationship between sampling interval and water table position apply. Moreover, the exact water table level will not be known since it is not practicable to install a piezometer within the sampling borehole.

The sampling network

The sampling network should incorporate suitable existing water supply sources 1/, naturally flowing springs and purpose-built sampling installations. The location of the latter will depend on the location of water supply and sanitation units and on the direction of groundwater flow.

1/ Samples may already be collected as a matter of routine from public supplies.

Since the main area of concern is the possible contamination of groundwater supplies, existing water supply sources provide an obvious focal point for the sampling network. Sampling sites should be concentrated around major sources of supply (as defined in Section II-E) and generally located between sanitation and water supply units. In areas served by small water supply units several of these should be selected, say, three in each project area, and sampling sites located between the water supply and nearby sanitation units, particularly up-gradient of the supply site. At least one sampling site should be located up-gradient of the pollution source to establish background conditions.

Each type of disposal unit may pose a different pollution hazard and the monitoring network should enable close study of each and an assessment of that hazard. For this purpose a minimum of three sampling points down-gradient and one up-gradient of the disposal unit is necessary. Sampling points should preferably not be within 5 m of the disposal unit and will not usually be useful at distances greater than 50 m (except in fissured aquifers).

Figure 3.2 shows a suggested sampling network in an African village where dwellings and consequently sanitation units are fairly widely spaced.

In some areas, contrary to normal recommendations 1/, wells (or boreholes)

1/ It is usually advised to have a protected area of at least 15 m radius around each groundwater source: see also Figure 6.2 in Lewis et al. (in press) for guidelines for appropriate spacings.

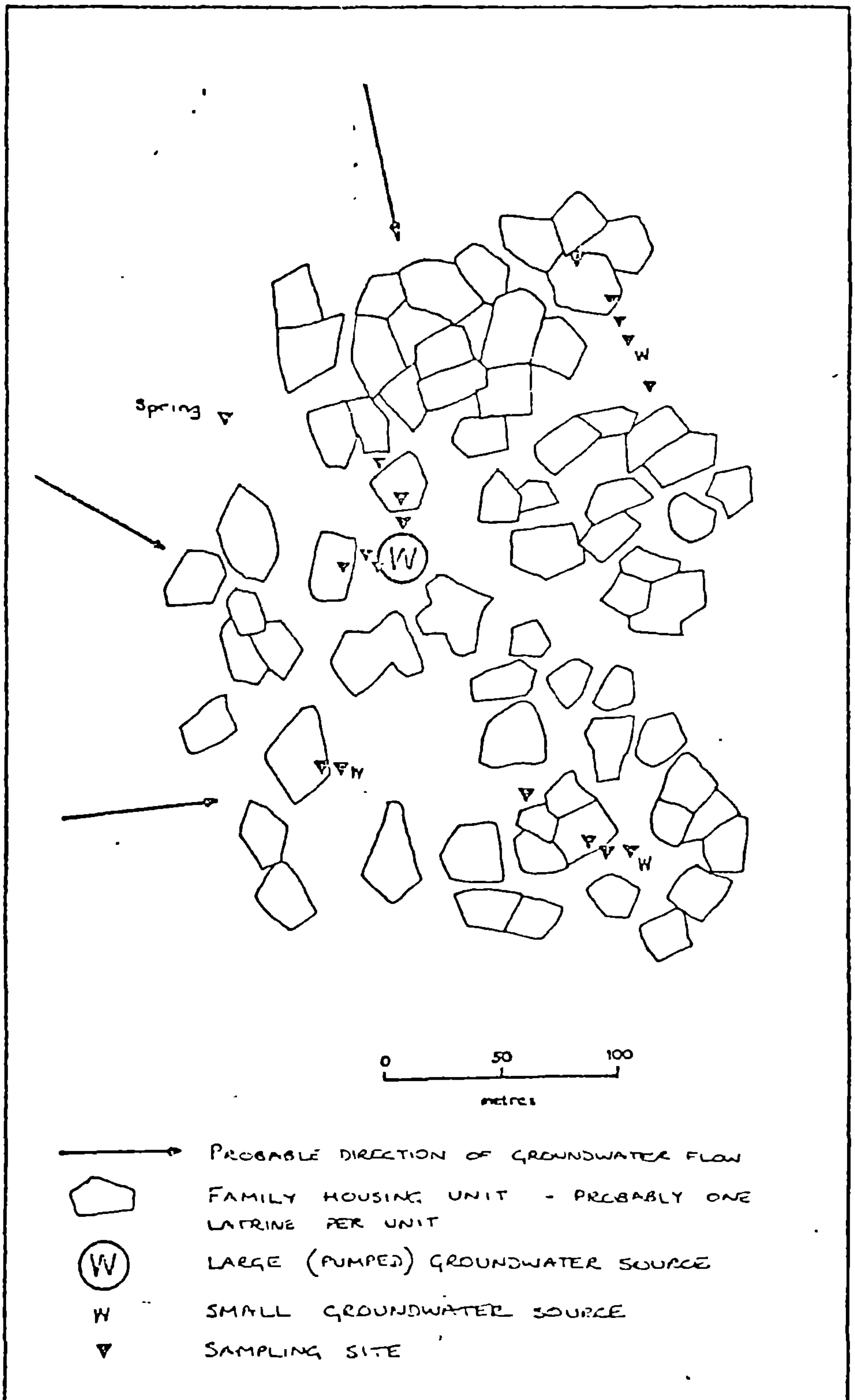


FIGURE 3.2 : THE SAMPLING NETWORK

and latrines may have already been installed only a few metres apart (sometimes even less than 5m) 1/. Figure 3.3, for example, illustrates the water supply and sanitation arrangements in part of a densely populated urban area in India. Under these conditions the preceeding guidelines may be impractical. It is important at least to sample specifically from the water table between the latrine and well or borehole and to monitor the quality of the well water at frequent intervals.

In areas of high density housing it may also be more practical to monitor the effects of a group of sanitation units rather than to isolate the effects of a single latrine. This may be especially appropriate where a community is to be provided, over a short period, with on-site sanitation at the individual household level.

Where the provision of sanitation is piecemeal it not only makes the pollution protection of groundwater supplies more difficult (Lewis et al, in press) but also causes practical problems in designing and operating a monitoring network.

It is also obvious that in these high density housing areas where all the land is occupied the cooperation of landowners and occupiers is essential: there may be problems of access or abuse of sampling installations. In all cases the precise location of sampling

1/ This proximity is inevitable where aspirations for the provision of sanitation and water supply at the individual private (family or dwelling) level have been realized without due regard for preserving water quality. In most of these cases the wells should be filled in and water supplied from more distant sources, by reticulation mains to each household or compound if possible.

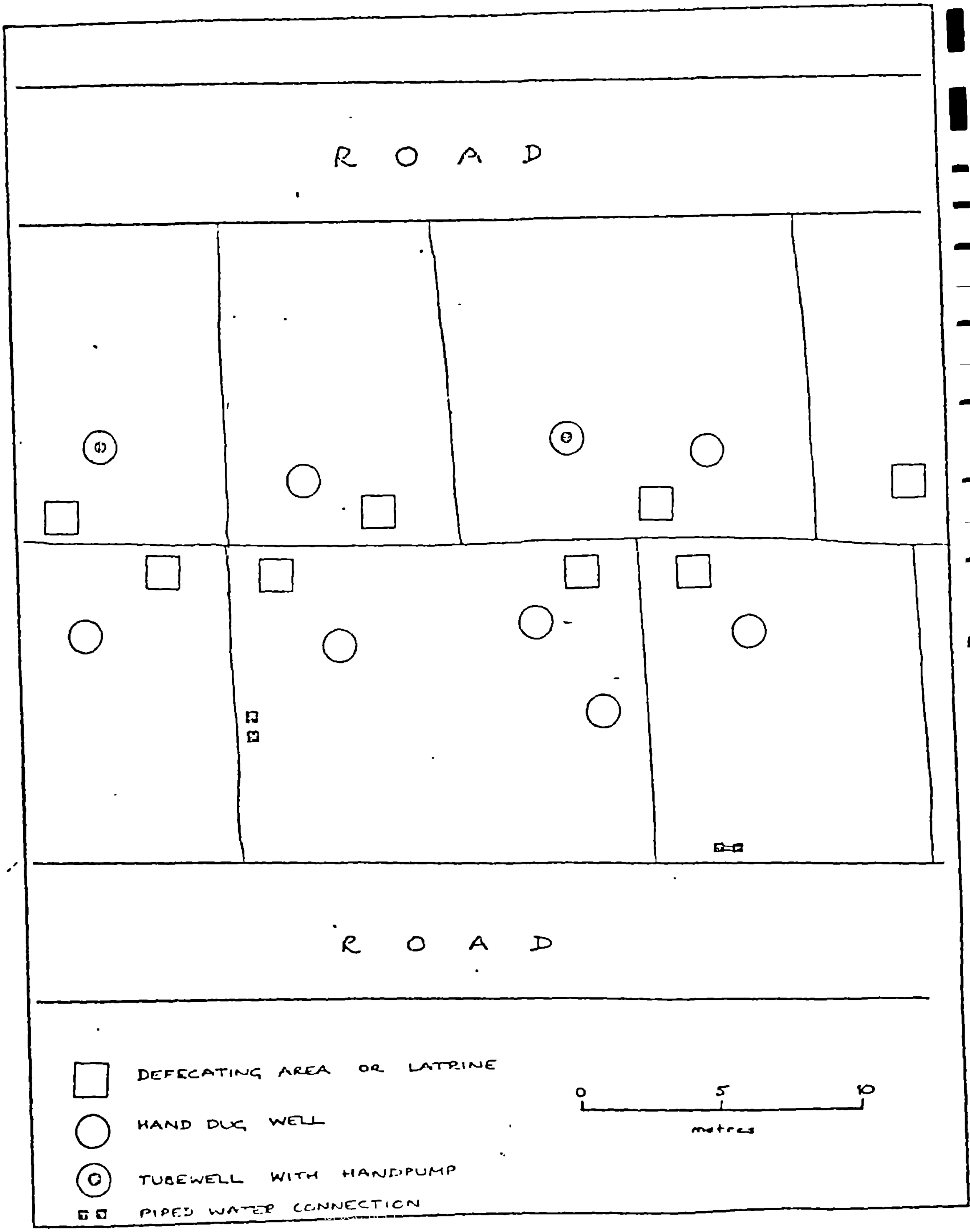


FIGURE 3.3 : WATER SUPPLY & SANITATION ARRANGEMENTS IN AN URBAN AREA

installations (and observation boreholes) will depend on such practicalities as accessibility and land use.

The number of purpose-built sampling installations will be limited by cost and it is likely that more money will be made available for monitoring purposes where the risk and cost of pollution is highest.

Frequency of sampling

Sampling intervals should be such that no significant changes in quality could pass unnoticed between sampling times. Groundwater movement under most natural conditions is slow, in the order of metres per day and so any quality changes within the groundwater body are likely to be equally slow. Close to a pollution source and particularly a new on-site sanitation system, changes in water quality may be more rapid and so it may be useful to take samples more frequently from nearby sampling points. Also more rapid changes may be recorded where fissure flow is significant and during periods of recharge, especially immediately following a period of drought at which time samples should be collected for analysis.

It is recommended that sampling be carried out on a weekly basis initially but this can probably be reduced to a monthly programme after 3 to 6 months provided the site conditions remain unchanged and the sampling period has included the first wet season recharge period (Table 5.1) Experience and an awareness of the implications of the analytical results will provide the best guide for the sampling frequency in any project area.

E. Duration of monitoring period

It will have become apparent from the preceeding paragraphs that a monitoring network will involve considerable cost especially in terms of manpower, both in the installation and operational stages. It should not be entered into lightly since its results are crucial to planning further development of water supply and sanitation schemes. Nor can valuable results be obtained quickly. The monitoring period should normally continue for at least 3 years. Ideally the monitoring phase should commence at least one year prior to the installation of sanitation units in order that background data can be obtained. Following installation of sanitation units monitoring should continue intensively for at least one year when the situation should be reviewed: depending on the results it may then be possible to reduce the intensity of operations. In certain hydrogeological environments particularly where the unsaturated zone is thick (say, > 5 m) it may take a much longer time before the full effects of installing on-site unsewered sanitation systems are felt.

IV

WATER QUALITY SAMPLES : HANDLING AND ANAYLSIS

The main aim of a monitoring programme is to detect changes in groundwater quality that may occur as a consequence of the installation of on-site sanitation. A monitoring network should be established and groundwater samples collected systematically for analysis.

A. Pollution indicators

It is expensive and unnecessary to subject all water samples to a complete microbiological, chemical and physical analysis: rather samples should be analysed for certain key constituents which are indicative of faecal pollution. These indicators are not necessarily harmful in themselves but point to the probable presence of pathogens or harmful chemicals. This report advocates routine monitoring of certain microbiological, chemical and physical indicators which are listed in Table 4.1 and discussed below.

(a) Microbiological indicators

It is recommended that routine microbiological analysis be restricted to the enumeration of faecal coliforms and faecal streptococci 1/. These two faecal bacteria are not completely ideal indicators of pathogen presence 2/ and there has been some criticism of their suitability for this purpose in hot climates 3/. However, the isolation and enumeration of specific pathogenic organisms involves sophisticated and lengthy techniques and it is not recommended that this be undertaken

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1/ It is important that samples are analysed for both these faecal bacteria as in some samples faecal coliforms may be absent but faecal streptococci present. Also, see D.D. Mara & R.G. Feachem (1979)

2/ See R.G. Feachem et al (in press) for characteristics of an ideal indicator bacterium.

3/ For example, see L.M. Evison & A. James (1973).

Table 4.1 : Pollution indicators : routine water quality monitoring

Type	Indicator	Comment
Microbiological	faecal coliforms	Portable field kits available for membrane filtration
	faecal streptococci	
Chemical	chloride	Stable: laboratory determination acceptable
	nitrate	Unstable: preferably determine in field; otherwise preservation necessary for st[illegible]
	nitrite	Attempt only if Hach 1/ or similar field kit available
	ammonium	
	iron	
Physical	electrica' conductivity	Simple to measure in field
	temperature	Must be measured in field at time of sampling

1/ Hach Chemical Company, Iowa, U.S.A.

on a routine basis. Viruses in particular typically occur in very low concentrations and the collection of sufficient water samples becomes an additional problem.

(b) Chemical (inorganic) indicators

Of the inorganic constituents it is recommended that both chloride and nitrate concentrations should be monitored as a matter of routine. Chloride is present at high concentration in urine: it is an extremely mobile and relatively inactive ion and therefore can be a useful groundwater tracer; also satisfactory methods are available for its determination even in low concentrations. Nitrate is similarly mobile and commonly associated with pollution from human or animal excreta.

However high chloride and nitrate concentrations are not necessarily indicative of pollution from human excreta. High chloride levels may also result from saline intrusion in coastal areas, from leaching of saline soils, especially in irrigated and semi-arid areas, and occasionally from leaching of salts from the aquifer materials themselves. High nitrate levels may be caused by various agricultural practices, in particular the application of fertilizers.

Nitrate is the end product of an oxidation process whereby nitrogen, which is present in excreta mainly in the form of organic compounds (principally urea), is converted to ammonium, nitrite and eventually nitrate. This process can only occur in the presence of oxygen and so in anaerobic groundwaters some nitrogen may remain in the form of ammonium or nitrite ions. The presence of ammonium and nitrite may also be indicative of recent pollution. Laboratory determination of these nitrogen forms, which usually occur only in very low concentrations, is difficult and this report only recommends their quantification when simple and reliable field test kits are available 1/.

In addition it is suggested that the iron content of the groundwater should be monitored particularly where this is obviously high 2/. This will give a general indication of the oxygen status of the groundwater which will be valuable in assessing the results of the chemical and bacterial analyses. Analysis for iron may be carried out less frequently, say 3-monthly, as the purpose is to establish background concentrations. The iron is derived largely from the aquifer and overlying materials and so concentrations would not be expected to alter significantly with time.

(c) Physical indicators

Electrical conductivity provides a rapid estimate of the total dissolved solids content of the water and can be easily measured in the field using a portable instrument 3/. Where low background conductivities have been established high values of conductivity

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1/ As obtainable, for example, from Hach Chemical Company, P.O. Box 207, Ames, Iowa, 50010, U.S.A.

2/ This may be apparent from rust-coloured staining.

3/ Conductivity meters have proven reliable under a wide variety of field conditions: they are simple and quick to operate. Conductivity is temperature dependent and conductivity meters should preferably be equipped with a temperature compensator.

may indicate high chloride concentrations associated with faecal contamination.

Temperature should also be measured in the field at the time of sampling:this can easily be done using a mercury filled thermometer. Temperature significantly effects bacterial survival. Also for pumped samples it is useful to measure groundwater temperature to ensure that samples are representative of the groundwater in the aquifer (see Section III).

B. Sample handling: collection, preservation and storage

It is essential that great care is taken over the collection, handling and storage of water samples. It is important that the samples are representative, are not contaminated during or after collection and have not deteriorated prior to analysis. Certain physical, chemical and biological changes inevitably occur after the sample is removed from its source so that as far as practicable tests should be carried out in the field. Where samples have to be transported to a laboratory for analysis the changes can be minimised by appropriate methods of storage and preservation.

Certain procedures are recommended below for the collection, storage and analysis of water samples. A full account of the techniques can be found in the joint publication of the American Public Health Association, the American Waterworks Association and the Water Pollution Control Federation entitled "Standard Methods for the Examination of Water and Wastewater" (15th Edition, 1980) 1/.

1/ Hereinafter referred to as Standard Methods.

Size of sample

Two separate 500 ml samples should be collected, one for bacteriological examination and the other for chemical analysis.

Collection

Samples should be collected and stored in wide-mouthed bottles that can be sterilized, preferably made of borosilicate glass (for microbiological samples) or polypropylene (for chemical samples) with stoppers of the same material.

Before each use sample bottles must be cleaned carefully (using a suitable laboratory grade detergent) and then rinsed thoroughly with potable water and finally distilled or deionised water. Those used for microbiological samples must be sterilized 1/ and should be kept stoppered until the moment each is to be filled; they should not be rinsed and special care must be taken to avoid contaminating the neck of the bottle or stopper by handling. The outlet pump or pipe conveying the sample must also be sterilized, usually by flaming with alcohol. For the sample collected for chemical analysis the sample bottle must be rinsed three times with the water being collected and at least 25 mm of air space should be left in each bottle to facilitate mixing of the sample by shaking prior to examination.

Each sample bottle must be labelled with a reference number 2/ and for each a record must be kept of the following information (as applicable):

1/ Satisfactory sterilization may be achieved by immersing in boiling water for at least 10 minutes.

2/ Masking tape and permanent marker pens should be provided.

Reference number

Exact location of the sample source

Method of collection

Depth from which sample collected

Water level

Pumped discharge rate (and length of time of pumping)

Date and time

Name of collector

Appearance of sample (colour, tubidity, odour)

Results of any field tests, (e.g. temperature, conductivity)

Filtration (size of filter, if any)

Preservatives added to sample

Borehole design and construction details.

A sample label is illustrated in Annex VIII. It is good practise to record the details on a separate field data sheet as well. This information should subsequently be copied onto the results sheet.

Filtration

For the basic level of monitoring recommended in this report it is not necessary to filter samples unless the water is cloudy in appearance. Samples for bacterial analysis in any case must not be filtered. For other determinations samples should be filtered and conventionally a filter with a pore size of 0.45 µm is used. Portable filtration systems allow samples to be filtered as they are collected. The filtration equipment must be kept absolutely clean and the first 100 ml or so of filtered water should be used to rinse the apparatus.

Storage and preservation

In general the shorter the time that elapses between collection of a sample and its analysis the more reliable will be the analytical results. If at all possible analyses should be carried out immediately in the field. Otherwise the samples should be stored in the dark and refrigerated. This is particularly important for bacteriological examination if the sample has to be kept for more than 1 hour: the elapsed time between collection and analysis should preferably not exceed 6 hours and never 30 hours. In the field it is often difficult, or impossible, to achieve the desired refrigeration but storage at 4°C is recommended. The duration and temperature of storage of all samples should be recorded.

Certain constituents can be "fixed" by adding a small amount of acid to the sample. For nitrate determination it is possible to preserve the sample by the addition of 0.8 ml concentrated H_2SO_4/litre of sample (however the sample must later be neutralised to pH 7 before analysis). Mercuric compounds ($HgSO_4$ or $HgCl_2$) may alternatively be used. Chlorides are more stable than nitrates and their concentration will not change significantly during storage.

C. Analytical techniques

Monitoring at the level recommended in this report should as far as practicable be carried out in the field although systematic confirmatory tests in the laboratory are also to be recommended. It is also recognised that field kits and portable instruments may not alwyas be available and so analysis may have to be carried out in the laboratory. Since it is undesirable to have to store samples for any length of time or transport them over long distances it may be necessary to set up a permanent or mobile field laboratory in the project area.

It is important to use standard laboratory methods and materials so that the analytical results are truly comparable for different samples and different analysis. Recognised procedures for the analysis of water samples in the laboratory are described in Standard Methods and reference should be made to this text: the more appropriate techniques are indicated below.

(a) Micro-biological analysis

Membrane filtration is the method of choice for enumerating faecal coliforms and faecal streptococci since groundwaters normally contain much lower concentrations of faecal bacteria and suspended solids than surface waters. The multiple tube or most probable number (MPN) technique may be used, but it is much more time consuming than membrane filtration (results take 3 to 5 days, rather than 24 hours) and it has to be done in a laboratory, whereas portable field kits are available for membrane filtration 1/; also membrane filtration is inherently a more precise technique.

1/ For example, fromMillipore (U.K.) Ltd., Heron House 109 Wembley Hill Road, Wembley, Middlesex, England.

The recommended analytical techniques (culture media, incubation times and temperatures) are detailed in Standard Methods and other publications 1/; commercial literature is also available and most useful 2/. The techniques described in Standard Methods are satisfactory, except that the incubation temperature for faecal streptococci should be 44°C (i.e. the same as for faecal coliforms), rather than 35°C, because the latter temperature permits the growth of non-faecal streptococci.

(b) Chemical analysis

For the chemical analysis of water samples several field kits are commercially available 3/ which give reasonably accurate determinations and eradicate problems of sample storage and transport. Various sensitive instruments, such as colorimeters and spectrophotometers 3/ have been produced in recent years and help to remove the subjectivity inherent in many analytical techniques; some have been adapted for use in the field, are portable and run off rechargeable battery packs. These instruments on the whole are straight-forward to use, although calibration may present a problem. If they are not prohibitively expensive their use is recommended.

1/ For example, H.M.S.O. (1969) and D.D. Mara (1974). (British literature more commonly refers specifically to Escherichia coli rather than faecal coliforms in general)

2/ For example, from Millipore. (U.K.) Ltd.,

3/ For example, from Hach Chemical Company, P.O. Box 207, Ames, Iowa 50010, U.S.A., and Bausch and Lomb, Rochester, New York 14625, U.S.A.

Techniques for the laboratory determination of chloride and nitrate are listed below; these are recommended as being inherently sensitive and accurate but relatively simple to carry out and less demanding in terms of equipment than other equivalent methods.

For chloride determinations two volumetric methods are recommended:

(i) the Mohr (Argentometric) method using silver nitrate as the titrate and potassium chromate to indicate the end-point of the reaction;

(ii) the mercuric nitrate method, using mercuric nitrate as the titrate and diphenylcarbazone as the indicator; this method may be preferred as it is much less subject to interference from other ions than the Mohr method.

For nitrate analysis Standard Methods lists six tentative procedures but "all have severe limitations and results obtained on natural samples can best be classed as semiquantitative" (Sawyer and McCarty, 1978). Perhaps the most apprpriate method is:

(i) the cadmium reduction colorimetric method; this technique measures the sum of nitrite plus nitrate nitrogen, but since nitrite concentrations in groundwater are generally negligible (and in any case nitrite is unstable and rapidly alters to nitrate) the distinction is not normally important. The method is very sensitive and suited to low nitrate concentrations.

D. Resource constraints

Available expertise and laboratory facilities will normally be limited (often severly) by manpower and financial constraints in most developing countries. Nevertheless it should be realised that the analysis of water samples may be the most expensive component of the monitoring programme in the long term, in terms of both laboratory or field equipment and consumables and technician time. The procedures outlined above are considered to be the absolute minimum necessary for meaningful routine analysis of groundwater samples, and all due care must be taken to ensure the accuracy of the results as far as the techniques allow. The main disadvantage of a partial (rather than a full) chemical analysis is that it does not permit any check to be made on the results by balancing the cations and anions.

E. Full analyses

For a full understanding of groundwater quality and interpretation of specific pollution problems full analyses of selected samples may be needed. Constituents which may be of interest are listed in Table 4.2. Where the necessary expertise and technical resources permit samples may usefully be analysed for some or, in rare cases, all of these. This analysis should be carried out in adition to the monitoring of pollution indicators (described above). Certain of these constituents can be determined in the field using portable equipment; other determinations involve more complicated laboratory procedures. Details of the relevant techniques are outside the scope of this report; a full account of the analytical procedures can be found in Standard Methods. Expert advice must be sought if, for any reason, it is considered necessary to examine samples for excreted pathogens 1/.

1/ See, for example, F.A. Skinner and D.W. Lovelock (1980).

Group	Constituent	Ease of analysis	Field determination essential
Major cations	Calcium Magnesium Sodium Potassium Silica	Easy	
Major anions	Sulphate Bicarbonate Carbonate	Easy	✓ ✓ ✓
Minor anions	Fluoride Phosphate Cyanide	Moderately easy	
Environmental indicators	Eh pH DO TOC BOD/COD H_2S	Desirable but difficult sampling method is critical	✓ ✓ ✓ ✓
Trace Organics	e.g. Synthetic detergents (Alkyl benzyl sulphonates)	Difficult	
Trace Metals	e.g. Lead Chromium Arsenic Cadmium	Difficult	
Specific pathogens	e.g. Salmonella	Difficult: requires expert advice	

Table 4.2 : Other contaminants of groundwater

V

PRESENTATION AND INTERPRETATION OF DATA

It is easy for a data collection programme to be extended almost indefinately. It is thus important to reconsider from time to time whether the data currently being collected is useful and whether the data base could usefully be widened by monitoring other variables. As far as possible the data should be collated and interpreted as it is acquired so that the monitoring programme can be continually updated.

A. The presentation of data

The data should be presented in such a way that the significance of observations will be apparent to others who have not necessarily been involved in data collection and analysis. If this is done the monitoring programme is much more readily interactive with the planning stage for future groundwater utilization and development and the provision of sanitation systems.

Data may be presented in tables, graphs and maps. Lengthy tables of numbers are not always easy to interpret and the significance of observations is more easily conveyed by simple graphical techniques. Graphs are particularly suited to demonstrating changes in parameters with time. Spatial variations are readily illustrated by simple maps. Appropriate methods of presenting the data collected during groundwater monitoring programmes are suggested below.

Field data sheets

All field observations should be carefully recorded in a form that is comprehensible to others. The use of standard field data sheets is recommended as this makes data collation and analysis easier. In addition this is a convenient way of itemising data requirements so that the necessary observations are less likely to be overlooked in the field. However, the data sheets should not be so rigidly designed as to discourage additional comments about conditions at the sampling site or observation point, which may later be useful in interpreting the data. All field sheets and note books should be filed for future reference: it is surprising how often it is helpful to return to these original records. Sample data sheets are presented in Annex VIII.

Rainfall data

A bar graph should be plotted to show weekly total rainfall (Figure 5.1).

Groundwater level data

a) A groundwater hydrograph showing variations in water level with time can be plotted for each observation borehole (Figure 5.2). The hydrographs should be up-dated as the monitoring programme proceeds and new data is collected. Data from groups of adjacent boreholes can be plotted on the same sheet of paper: it is likely that the hydrographs will be similar and any anomalous observations can immediately be checked.

b) A water table contour map can be constructed to provide a rapid visual impression of the water table configuration in the project area (Figure 5.3). Since the water table usually fluctuates seasonally it is necessary to base the map on data collected at one particular time - either on one particular day or over as short a time as possible - or it might be useful to construct two such maps, giving maximum

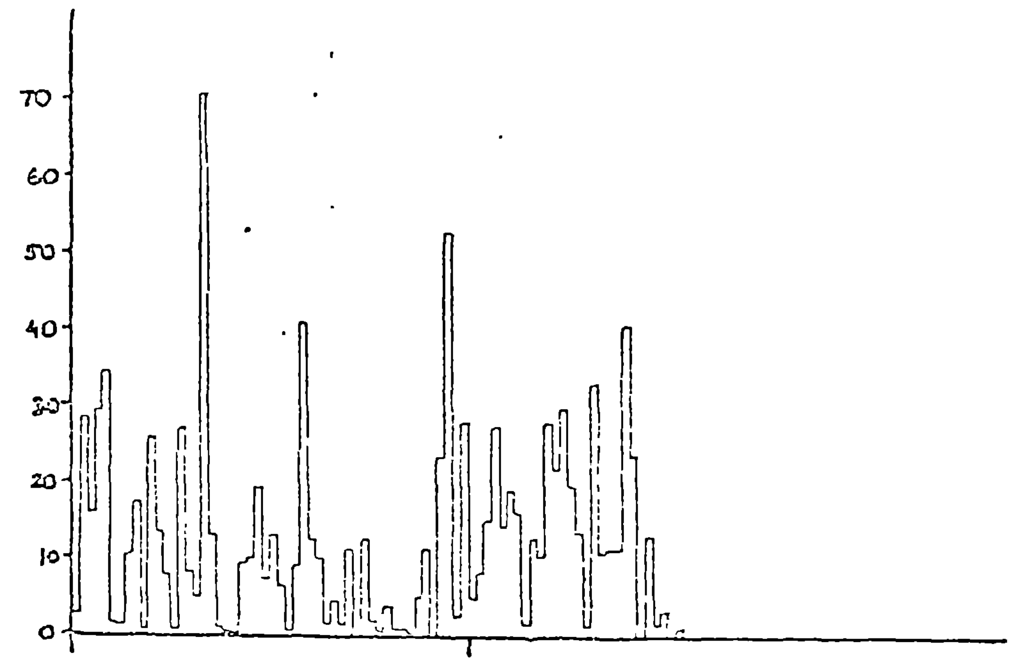

FIGURE 5.1 : BAR GRAPH - WEEKLY RAINFALL TOTALS.

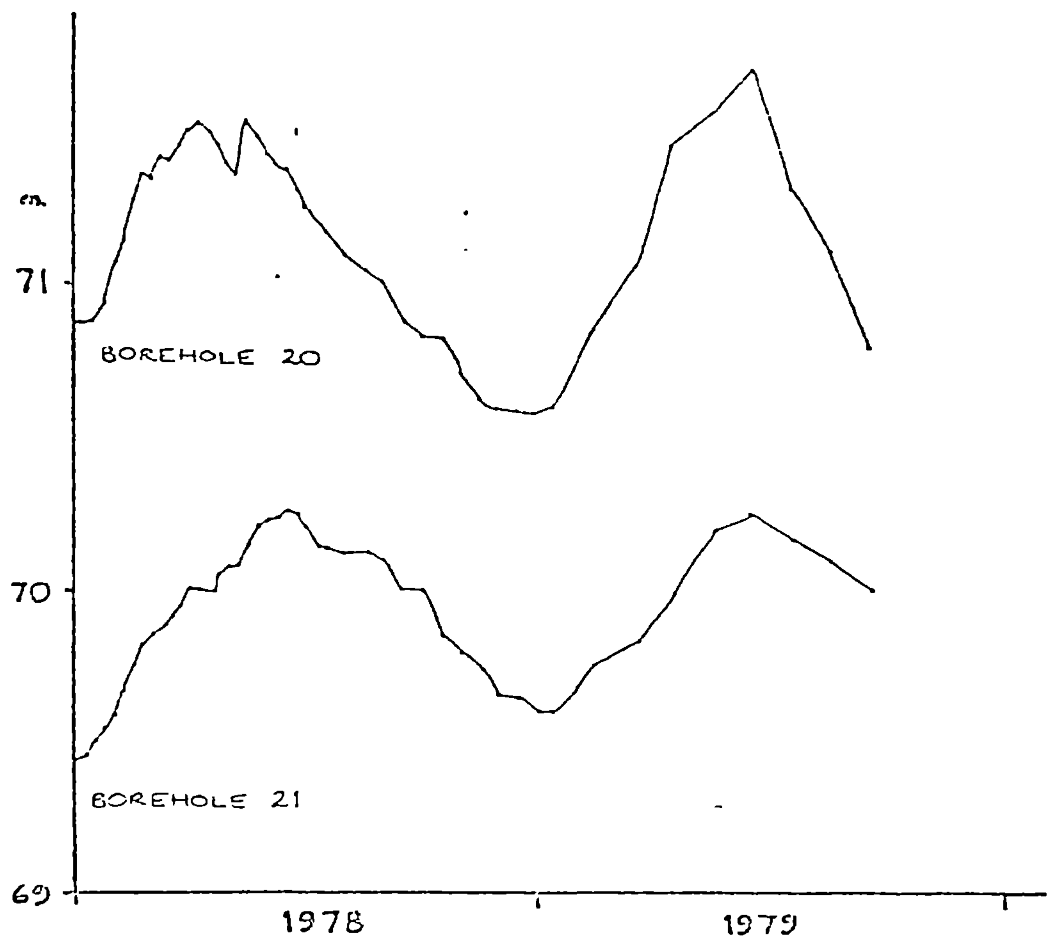

FIGURE 5.2 : GROUNDWATER HYDROGRAPHS

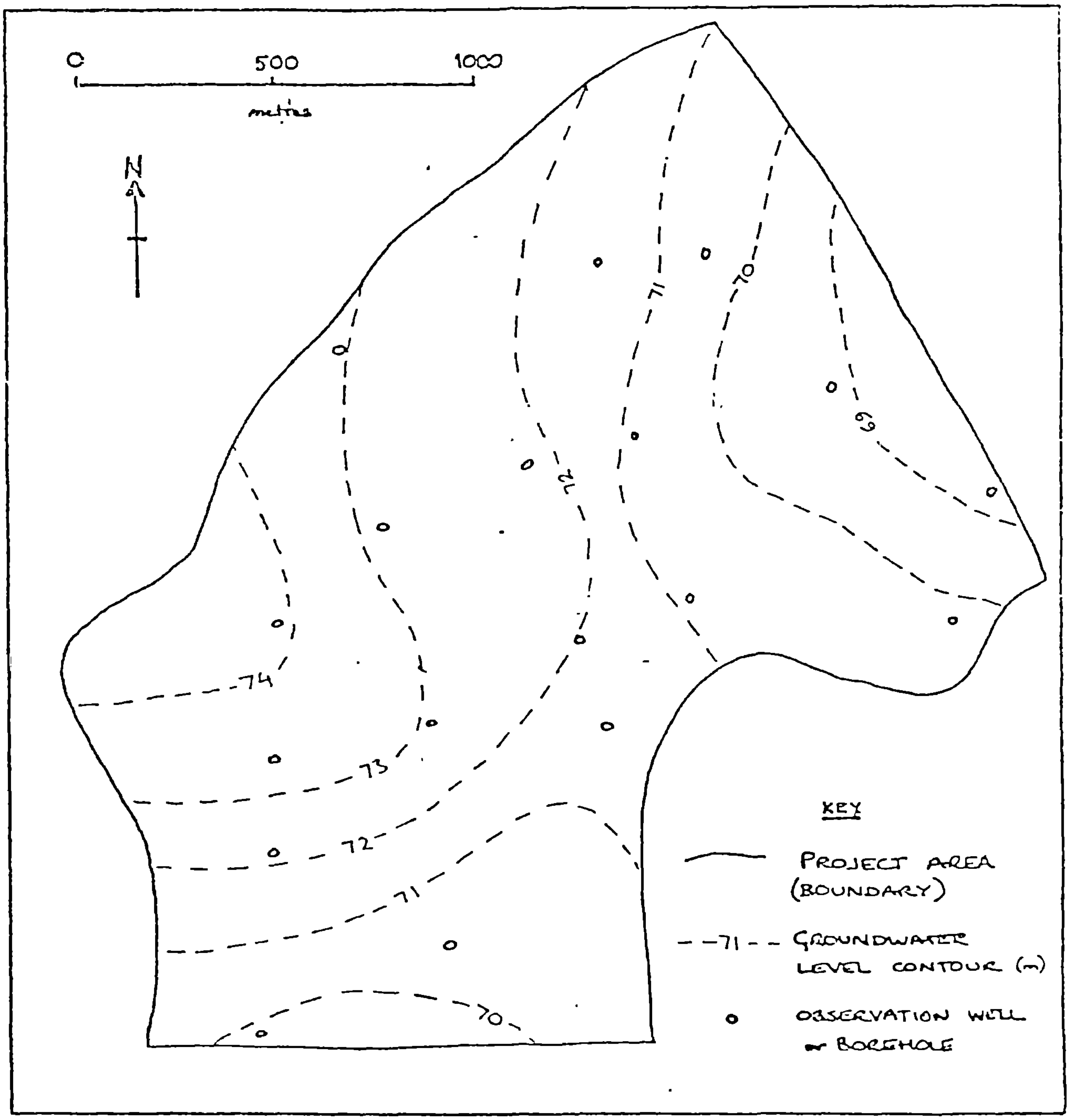

FIGURE 5.3: WATER TABLE CONTOUR MAP

and minimum groundwater levels 1/.

Contours are interpolated between the point data and the technique is inevitably subjective. Reference might usefully be made to a topographic map or aerial photographs of the project area and the location of major groundwater abstraction points that might create pumping cones of depression in the water table; otherwise, in the absence of contradictory evidence, it is usual to assume an approximately linear relationship between adjacent points.

It is useful to attempt to construct a water table map early in the monitoring programme. It will be readily apparent where data are insufficient to give a clear picture of the water table configuration and additional observation boreholes can be sited accordingly.

c) A depth to water table map may be useful in both planning borehole construction and sampler installation and interpreting water quality observations. However, it has to be developed from both the groundwater level map and the topographic survey so that it is rarely likely to be very accurate.

d) Hydrogeological cross-sections provide an alternative and better method of illustrating variations in geology and water level from one point to another and can help to build up a three-dimensional picture of the project area (Figure 5.4). Geological logs are better correlated in this way.

1/ It is obviously necessary to level in each borehole so that groundwater levels are measured with respect to the same datum.

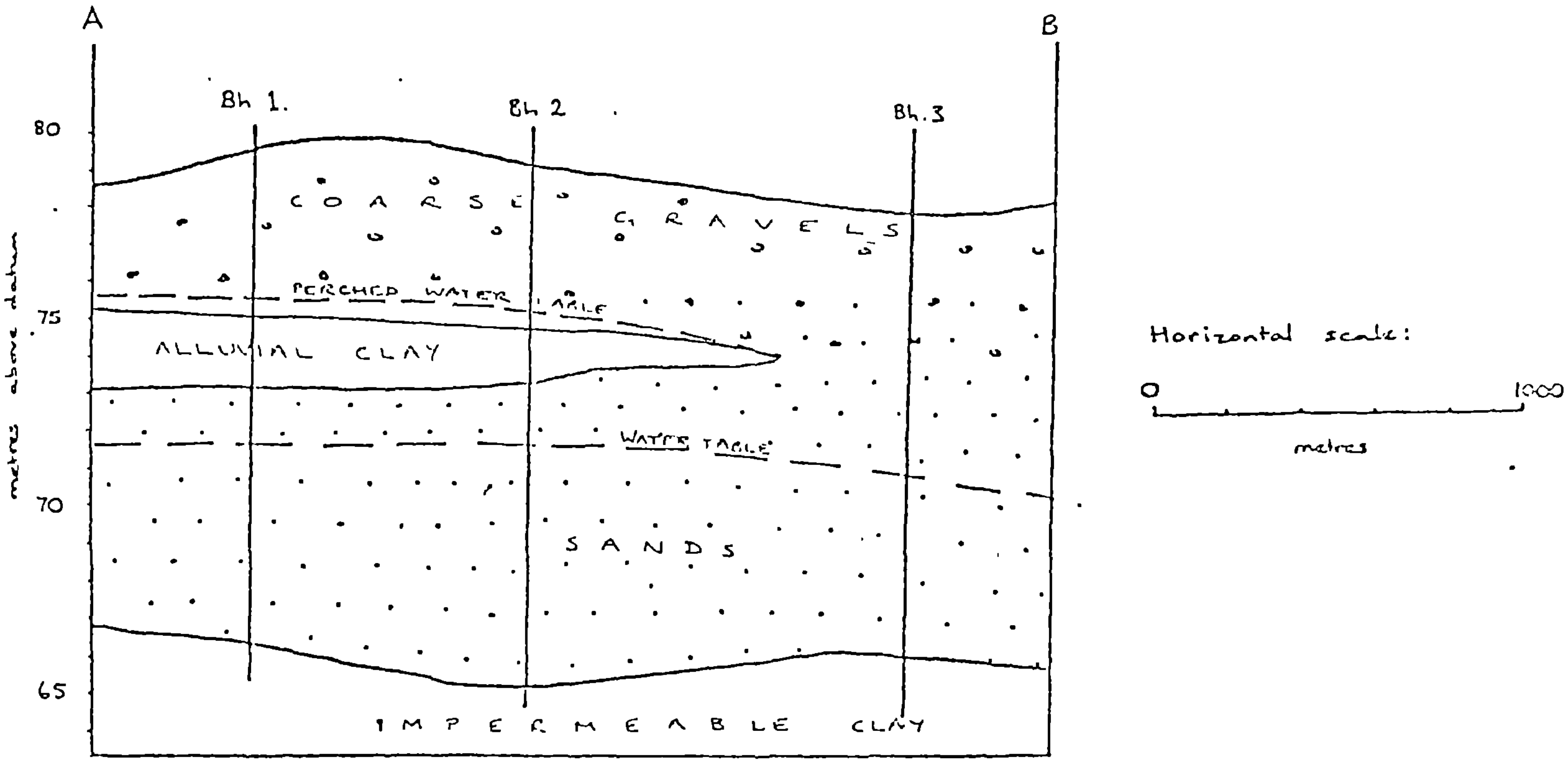

FIGURE 5.4: HYDROGEOLOGICAL CROSS-SECTION

Water supply and sanitation installations

The location of all waste disposal and water supply units and any reticulation (nothing where this is below maximum groundwater level) should be mapped. Different symbols should be used for different types and sizes of unit: a figure adjacent to the symbol can indicate discharge or hydraulic loading. It should be made clear which installations are recent and which well established and proposed sites should be marked. This "base map" will remain relatively unchanged and so it is a good idea to draw it on tracing film so that it can be used as an overlay for other maps of the same scale.

Water quality data

Analytical results should be tabulated. Chemical concentrations should be recorded in mg/l. Faecal indicator bacteria concentrations should be expressed as the count per 100 ml.

Water quality variations in time and space can be illustrated by hydrographs and simple maps in the same way as water level variations. Hem (1970) describes various types of graphs, maps and diagrams which help to show the relationships between sample analyses, but most of the techniques he describes are more appropriate where full analyses have been carried out.

a) Water quality hydrographs show changes in concentration of selected constituents over a period of time. The values for all indicators from one sampling installation, or the same indicator from a group of sampling points, should be plotted on the same sheet so that any pattern or trend is more readily apparent (Figure 5.5).

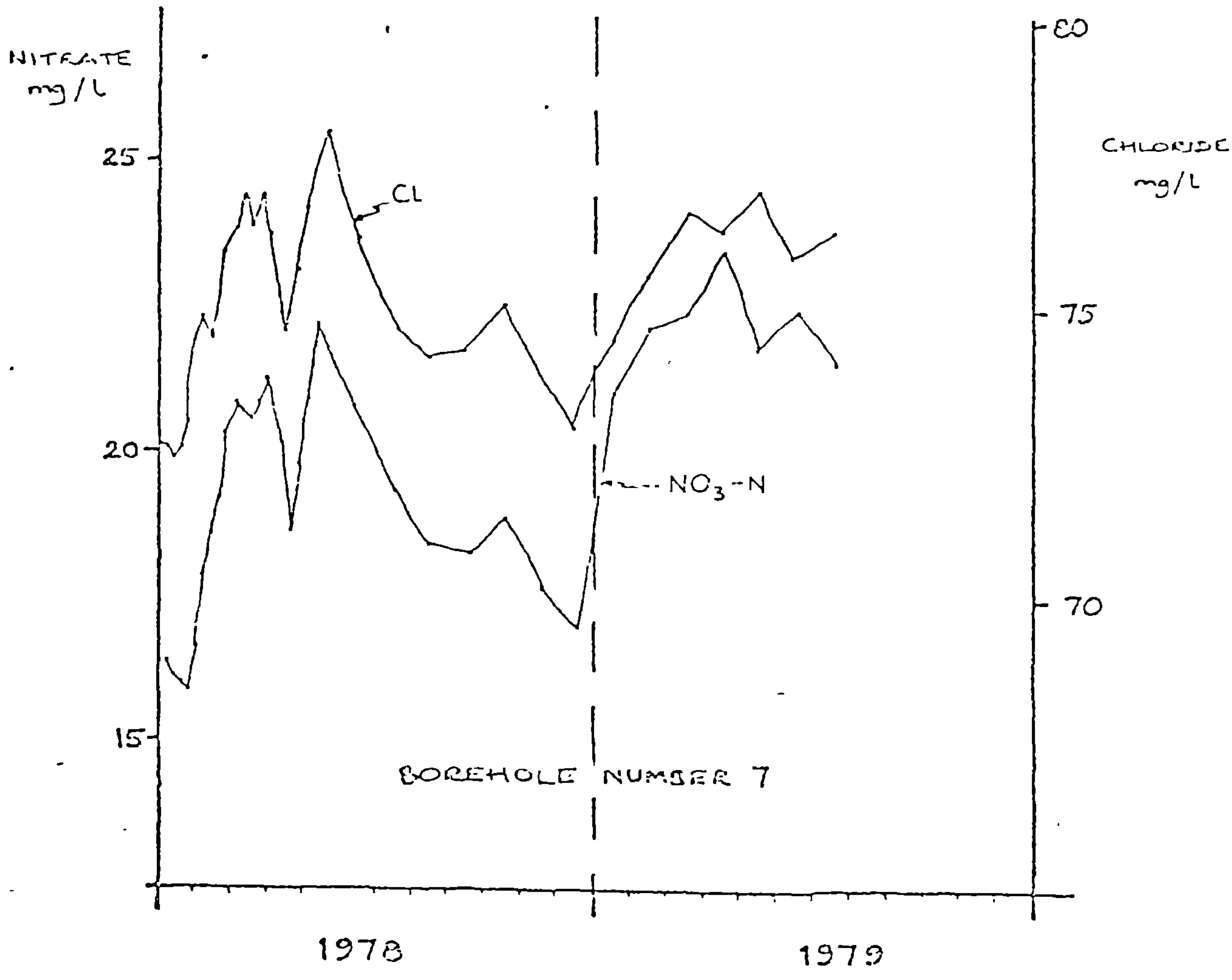

FIGURE 5.5 : WATER QUALITY HYDROGRAPHS

b) Water quality profiles show differences in water quality with depth and can be drawn when samples are derived from a number of different depths in the same borehole (or in nearby boreholes). Usually samples will be collected from only one or two depths and although they may be markedly different in composition there will be insufficient known values to warrant the construction of a water quality profile.

c) Water quality maps should indicate the areal extent of aquifer pollution A water quality map should be compiled early in the investigation. so that areas needing closer field study can be identified. Concentrations of constituents can be indicated by numbers or symbols at each sampling site (Figure 5.6). The symbol can be a bar graph or pattern diagram indicating relative concentrations of the pollution indicators. If there are sufficient sampling sites and samples are believed to have been collected from approximately the same depth below the water table at each site, then isograms can be constructed (Figure 5.6).

Correlation

A major reason for presenting data in a visual form is to aid comparison between variables. Significant relationships (which may be overlooked if the data is only presented in tables) are easily recognised from the similarities of hydrographs or maps. All hydrographs for both groundwater levels and groundwater quality and the plot of rainfall should be drawn to the same time-scale. Similarly all maps should be drawn to the scale of the base map. It is useful to use tracing film for the maps so that they can be overlain, so as to permit closer visual comparison.

Where a straight-forward visual comparison infers some relationship between two variables the correlation should be tested. The simplest correlation

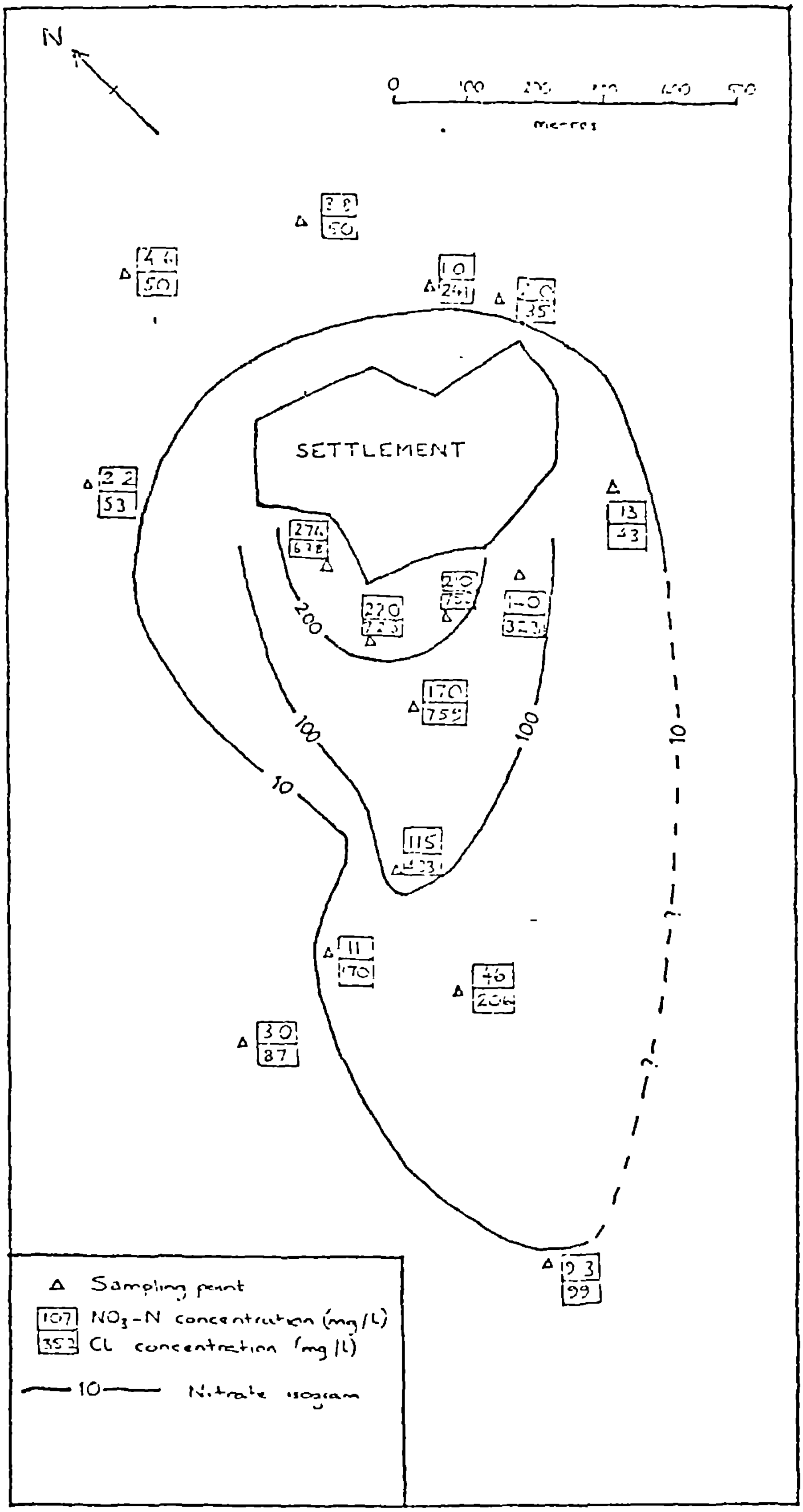

FIGURE 5.6 : WATER QUALITY MAP

procedure is to prepare a scatter diagram, with the two axes indicating, for example, concentrations of two different constituents (Figure 5.7). Data from all sampling points in the project area should be recorded on the same diagram. (Statistical, usually "least squares", procedures for fitting a regression line to the scatter points and evaluating the goodness of fit by a correlation coefficient give a numerical value to the correlation.)

The above techniques are themselves approximate but the out-of-sight nature of groundwater inevitably limits the extent of knowledge that can be acquired about any one aquifer and it is a mistake to allow the apparent precision of water quality data, for example, to mislead. With the procedures outlined in this report it is only possible to obtain data from scattered points and interpolation between these points will necessarily be subjective.

B. Interpretation of data

All those involved with data collection and collation should be aware of the significance of the data and in particular be able to recognise major anomalies. Detailed interpretation of the data may require the skill and experience of a specialist, but the major implications should be easily discernible if the data is clearly presented. The comments below may help the non-specialist to understand the significance of the data.

Rainfall is recorded primarily to give an indication of periods of infiltration and aquifer recharge. This is significant because the contaminants will only move through the unsaturated zone in the percolating recharge water. During periods of drought the pollutants are stranded in the soil. The plot or rainfall data will clearly show any seasonality and also the onset of rains following a long drought period, which may be the most critical period for aquifer pollution.

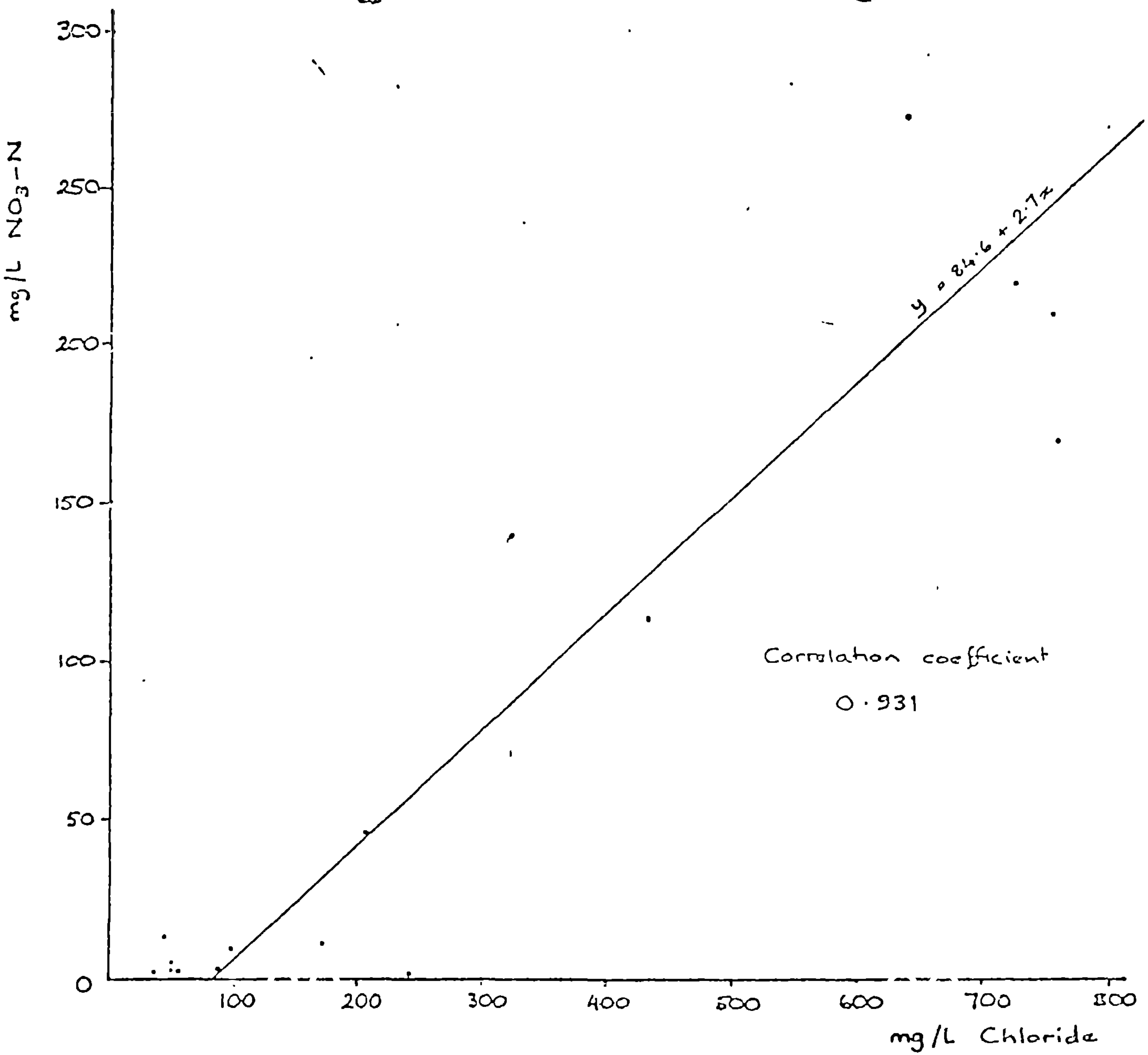

FIGURE 5.7 : SCATTER DIAGRAM

Visual comparison of the rainfall plot and groundwater hydrographs may reveal similarities although a hydrograph is an expression of the more complex storage conditions of the aquifer. Recharge may appear to be limited to the rainy season or may occur spasmodically in response to isolated rainfall events. The lag time between the peaks of the rainfall plot and well hydrographs gives an indication of the residence time of water in the unsaturated zone.

Fluctuations in groundwater indicated by the groundwater hydrographs are significant for four reasons:

(i) a rising water table implies recharge which may transport pollutants into the aquifer;

(ii) a falling water table may cause certain constituents of the water, such as bacteria, to become temporarily stranded in the soil; they may be remobilised when the water table rises again, thus causing cyclic fluctuations in water quality;

(iii) the depth of the source of a water sample in relation to the water table and the thickness of the sampling zone where this includes the water table, will vary with fluctuations in groundwater level and groundwater quality often changes with depth; and

(iv) the range between observed maximum and minimum groundwater levels is critical in the design of sampling and observation boreholes.

The groundwater level at the time of sampling should be ascertained for each sampling site. This may involve some interpolation since groundwater levels will be known for observation boreholes but not for all sampling sites. Water level maps make this interpolation easier.

The direction of groundwater flow is also determined from water level maps. The flow lines are at right angles to the water table contours and the flow is down-gradient.

A depth to water table map gives a quick impression of the variation in thickness of the unsaturated zone in the project area and may be useful in planning the location of sampling sites and the construction of observation boreholes. Anomalous groundwater levels may indicate perched water tables. This case will often become more obvious from hydrogeological cross-sections. By this technique the geology between logged boreholes can be interpolated to give the depth and thickness of the aquifer at any point.

Fluctuations in water quality, demonstrated by water quality hydrographs, may be the result of several factors. For example, a decrease in concentration of a specified indicator may be the consequence of

(i) dilution by dispersion;

(ii) reduction in the quantity of the indicator reaching the saturated zone, due to either improved efficiency of soil defence mechanisms leading to greater natural attenuation or a reduction in the initial occurrence of the pollutants;

(iii) the indicator being stranded temporarily in the unsaturated zone by a falling water table; or

(iv) samples being obtained from a different depth within the groundwater body.

It is more important to detect any trend remaining after cyclic or random fluctuations have been removed. A general decrease in pollutant concentration probably represents either of the first two cases, or a combination of the two. The most likely cause of a long-term upward trend, that is an increase in the concentration of the pollution indicators, is an increase in the pollutant load and probably an increase in the area of infiltration offered to the pollutants: in this context this probably corresponds to the recent installation of on-site sanitation units.

If the pollution is derived from human excreta, corresponding increases in all the indicators would be expected. If on the other hand there is only an obvious increase in one constituent, chloride perhaps, then this may derive from another source.

A water quality map, especially one with isograms, may help to show sources of pollution or recharge areas and directions of water movement. Concentrations of pollution indicators would be expected to be highest near the source of pollution. Anomalous patterns may be the result of fissure flow.

It is evident therefore that groundwater hydrographs and water quality plots should be compared; the former may help to explain changes in groundwater quality with time. Spatial variations may be explained by comparing water level maps with quality maps and by reference to the base map showing the location of waste disposal sites and water supply sources.

Thorough interpretation of the data collected in the monitoring programme will become easier as the interpreter gains more experience and a "feel" for the hydrogeological conditions of the project area. Meanwhile the most important water quality observations are those which indicate no change from the background concentrations observed prior to the installation of sanitation units. Furthermore, in favourable hydrogeological environments these 'negative' results may be the most common.

C. Extrapolation of results

The project area should have been selected as representative of a wider region and so the results of the monitoring programme should be capable of extrapolation. It may be expected that the observations in the project area would have been repeated outside that area where site conditions - including geology and soils and density of water supply and sanitation units - were similar. The extrapolation of the results outside the project area requires some knowledge of prevailing conditions and this may be lacking. A rapid survey may suggest where environmental conditions and levels of service for water supply and sanitation are similar.

VI

RECOMMENDED ACTION AND CONCLUDING REMARKS

A. Follow-up action

There is little point in pursuing a lengthy and costly monitoring programme if this is not followed up by the appropriate action. This action will of course depend on a number of factors which may be social, political and economic rather than purely hydrogeological and may be specific to the region. Of particular relevance is the quality of alternative water supply sources: groundwater, although polluted, may in fact provide the most attractive alternative. The results that emerge from a monitoring programme fall into three major catagories:

(i) No change in groundwater quality,
(ii) pollution of sampling points (but not water supplies),
(iii) pollution of water supply sources.

Guidelines for the appropriate action in each case are given below.

(i) Where there is no apparent change in groundwater quality it may be assumed that any groundwater supplies remain safe. The monitoring frequency may be reduced so long as a routine check on the quality of water supplies is maintained. If further sanitation units are installed then intensive monitoring must continue as this could cause a change in the groundwater quality.

(ii) An early warning of aquifer pollution may be provided by the detection of pollutants in groundwater sampled up-gradient of water supply sources. A close check should be kept on the groundwater quality at both the sampling site and supply borehole to determine whether an equilibrium has been attained or pollution can be expected to worsen. In particular the degree of microbiological pollution should be ascertained.

A major water supply source may encourage the migration of pollutants towards the source by creating a cone of depression in the water table. It might be advisable to reduce or cease pumping. No new water supply units should be installed down-gradient of the sanitation units.

Closer study should be made of the pollution sources, in particular their hydraulic loading. Modification to the design or usage of the sanitation units may reduce groundwater pollution, or the decision may be to fill in and abandon the units.

(iii) Immediate action is necessary where water supplies are contaminated. Further sample analyses may confirm the source, degree and hence seriousness of pollution. A common source of pollution to an aquifer is the borehole or well itself; the construction should be checked to ensure that there is no pathway for pollutants to enter the well.

If the water is heavily polluted with bacterial contaminants the source should preferably be abandoned, unless available alternative sources are more badly polluted. Where this is impractical the degree of pollution should be ascertained by a more detailed analysis of the water samples: samples should be sent to a laboratory where tests for pathogenic organisms can be carried out. The water must be treated to render it potable (Howard, 1979; Cairncross & Feachem, 1978)

It should be remembered that these guidelines refer not only to water supply and sanitation units within the project area, but also they should be applied where similar conditions prevail outside the confines of the project area. The results of the monitoring programme may suggest other water supplies which should be closely monitored for changes in quality.

B. Concluding remarks

In the preceeding sections a methodology for the development and implementation of a monitoring program is presented. The specific purpose of the monitoring program is to detect changes in groundwater quality caused by the installation of unsewered sanitation units: the aim is to detect groundwater pollution before it causes contamination of groundwater supplies. Where water supply or sanitation services have yet to be installed a monitoring programme should be implemented to establish background conditions; the results will help in planning the location and design of water supply and sanitation facilities.

The cause of variation in groundwater quality must be established: quality variations may reflect changes in site conditions quite apart from sanitation installations. Adverse changes may result from other pollution sources, changes in hydrogeological conditions, inconsistency in sampling techniques or careless sample handling. The collection of representative groundwater samples is just as important as the analysis of samples: they should preferably be analysed in the field, otherwise every effort must be made so that the quality of the samples remains unchanged when they reach the laboratory.

The analytical results and all field data should be clearly and accurately recorded, together with any information about site conditions or laboratory techniques which might shed light on anomalies. Data should be presented so that its significance is apparent to those not concerned with its collection. All records should be kept on file for future reference.

The establishment of a monitoring network involves considerable expenditure in terms of time and money. This expense is clearly justified when good use is made of the data and decisions are based on the results of the monitoring programme. The decision may be that no action is required or perhaps that a water supply source should be abandoned or treatment recommended: in either case the decision rests on the correct interpretation of the hydrogeological and water quality observations.

Monitoring is a continuous process and should continue beyond this initial decision-making stage. Groundwater quality is continually changing in response to changing site conditions, hydrological factors and the degree to which natural attenuation processes operate in the unsaturated and saturated zone. After a period of time a different course of action may be appropriate. Ideally the monitoring programme should continue for at least three years after the water supply and sanitation installations have been completed.

The procedures for establishing a monitoring network involve three overlapping stages:

(i) Planning and design
(ii) Construction
(iii) Operation

At certain times it is possible that all three stages will be proceeding simultaneously. Because in general the longest record is often the most useful, monitoring should commence as soon as facilities become available. Data collected during these early stages may be crucial in determining the most appropriate locations for further observation boreholes and sampling sites.

The proposed sequential procedure for the development of a groundwater quality monitoring programme in connection with on-site sanitation installations is presented below:

1. Select project area.
2. Install rainfall station, or check reliability of existing station.
3. Site appraisal desk study.
4. Site appraisal field study.
5. Limited drilling programme for water level observation boreholes.
6. Collate data as available. Review plan for monitoring network.
7. Drilling programme for the installation of further observation boreholes and sampling installations.
8. Systematic monitoring programme for rainfall and water level observations.
9. Systematic programme for the collection and field analysis of groundwater samples.
10. Laboratory analysis of groundwater samples.
11. Collation and presentation of field data and analytical results.
12. Interpretation of "results".
13. Extrapolation of results to a wider area.
14. Follow-up action.

No simple set of guidelines can be appropriate for all situations. The purpose of this methodology is to assist in the design and implementation of a monitoring programme suitable for a specific project area. A basic monitoring network and programme are suggested which should be within reach of the limited financial and technical resources of developing countries. It should be stressed that this is the minimum requirement for a meaningful monitoring exercise. Where financial constraints are less severe, the monitoring programme may usefully be extended or a complimentary research programme organised.

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