ENGLISH NATURE

Hydrology and mineral workings
Effects on nature conservation
Technical Annexe

No. 106 - English Nature Research Reports

working today
for nature tomorrow

ENGLISH NATURE RESEARCH REPORT

No 106
HYDROLOGY AND MINERAL WORKINGS

EFFECTS ON NATURE CONSERVATION

TECHNICAL ANNEXE

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March 1994

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ISSN 0967-876Y

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CONTRACT F72-06-34

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1.0 INTRODUCTION

1.1 The Minerals Industry and Nature Conservation

1.1.1 The extraction of minerals makes an important contribution to the nation's economy, providing a major source of aggregates to the construction industry, as well as a whole range of other industrial minerals and mineral-based products. However, along with other forms of development such as agricultural intensification or urban expansion this activity poses a potential threat to sensitive environmental areas either by direct loss or through indirect effects.

1.1.2 Mineral working may affect the local and regional hydrological regimes and unless controlled in a responsible manner this may lead to a detrimental effect on already established sites of nature conservation. The effects are different for different types of mineral, depending on the scale of operation, site topography or geology. In some cases the effects will be relatively localised; in others they can be highly significant over large distances. Some of the processes which are involved are reasonably well understood; others are not.

1.1.3 The restoration of former extraction sites is also extremely important to the ecology of what is essentially a man-made landscape. Worked out operations provide different habitats, adding diversity to the local environment, and in time many become sites of nature conservation importance in their own right. Furthermore, wetlands so formed in the flood plains of major rivers provide a vital role in attenuating flood waters. However, this has to be balanced against the preservation of existing areas of nature conservation interest and does not necessarily mitigate against the loss of other sites.

1.1.4 As conventional sources of mineral near to demand centres are consumed, so nature conservation sites adjacent to, or overlying remaining reserves will come under increasing pressure. In many of these areas, such as the gravel-filled valleys of the south east, the local hydrology is critical to the maintenance of sensitive habitats. Understanding the hydrological regime is therefore essential if the best use is to be made of both of these national resources.

1.2 The Guidelines

1.2.1 The Guidelines have been written primarily to assist English Nature conservation officers when assessing proposals for mineral extraction. However, they also aim to be of use to mineral operators and local authority planners by increasing the level of awareness and understanding of the potential hydrological impacts of mineral extraction, and by encouraging best practice in the identification, assessment and mitigation of impacts at specific sites.

1.2.2 An additional aim is that the Guidelines will help to create some uniformity of response by English Nature to planning applications and that some of the issues and solutions which are highlighted could be applied in individual circumstances.

1.3 The Technical Annexe

1.3.1 The Guidelines are published as a separate document. They are supported by the following report which deals in more detail with specific areas relating to the extraction industry and the water environment. This report forms the Technical Annexe to the Guidelines. In both documents the term "hydrological effects" can be taken to include "hydrogeological effects" and any other effect on the total water environment.

1.3.2 The Technical Annexe is not intended as a technical review or an in-depth treatment of all the hydrological issues but as a source of practical information. For this reason it considers some of the difficulties which are involved in relating hydrological and ecological change and includes a number of case studies. It is hoped that it will better explain the English Nature standpoint on nature conservation and will enable hydrologists and ecologists to communicate more effectively.

1.3.3 These documents have been deliberately restricted to **surface mineral workings,** ie., where the material is extracted directly from the surface after removal of the overlying material. **Deep mines** involving access from the surface of the mine through overlying strata are a separate subject in their own right and are not considered in detail here.

1.3.4 **Peat workings** are a specialist subject on which considerable research has been, and is currently being carried out. Although much of the Guidelines will be as relevant to peat sites as to any other extraction activity, there are particular impacts peculiar to peat workings which have not been included here.

1.3.5 The report is divided into four parts:

- **Part 1** describes the general background to the project in terms of the industry and nature conservation but also in terms of hydrology and ecology.

- **Part 2** covers activities involved in mineral extraction and how they may affect the hydrological regime.

- **Part 3** gives advice on how to assess the effects of a proposed development.

- **Part 4** provides guidance on potential mitigation procedures to prevent or ameliorate adverse effects to sensitive sites.

1.3.6 The report is illustrated by a number of case studies which have been taken from a variety of mineral workings around the country. Figures are located at the back of the report and a glossary of terms is also included for the non-technical user. Technical references are shown within the text as a small superscript number in parentheses, such as (1), and given in full in the list at the back of the report. However, references to Statute appear in full within the text and are not repeated in the reference list.

1.4 Origin of Guidelines and Consultation

1.4.1 The Guidelines and Technical Annexe were commissioned from MRM Partnership by English Nature under Contract Number F72-06-34. The reports were prepared by RUST Environmental, a division of MRM Partnership in consultation with staff from the following organisations, whose help is gratefully acknowledged:

- English Nature
- National Rivers Authority
- BACMI, SAGA, BCA and other trade organisations
- Mineral operators
- Local authority mineral planners
- The DoE (Minerals Planning)

2.0 INSTITUTIONAL BACKGROUND

2.1 Introduction

2.1.1 Over past centuries the countryside of Britain has undergone a major transformation, with the loss of many natural areas to development and through agricultural intensification and afforestation. The areas which remain are often under considerable pressure. Nature conservation is concerned with the wise and sustainable use of these natural resources to ensure that what remains of our natural heritage is maintained for future generations.

2.2 The Role of English Nature in Nature Conservation

2.2.1 English Nature (EN) is the Government funded body responsible for promoting nature conservation in England and replaced the Nature Conservancy Council in England in April 1991. Its responsibility is defined within Part VII the Environmental Protection Act 1990. In particular this is:

- to maintain and enhance viable populations of the characteristic flora and fauna of the country, over their traditional ranges
- to provide advice to the Secretary of State on the development and implementation of policies for, or affecting, nature conservation
- to select, establish and manage National Nature Reserves (NNRs) and to identify and notify Sites of Special Scientific Interest (SSSIs) - these may include sites of both ecological and geological interest
- to consider applications and issue licences to disturb or move protected species
- to provide advice and disseminate information about nature conservation
- to commission relevant research.

2.2.2 As a statutory body, the role of EN is both as advisor and consultee in major Planning Applications, particularly those involving SSSIs, and it is the statutory point of contact for both ecological and nature conservation issues.

2.3 Nature Conservation Designations

2.3.1 Designated sites are areas of high nature conservation importance which are protected to varying degrees by statute, international conventions or local authority planning controls. There is a general hierarchy in value which prioritises designated sites as follows:

- international/European/sites
- national sites
- regional or local sites
- other wildlife sites

2.3.2 Sites of Special Scientific Interest (SSSI) are the best examples of areas of special nature conservation interest and include flora, fauna, geological or physiographical features. Some are managed by EN as National Nature Reserves (NNRs), which have particular conservation interest. Others are managed by local voluntary conservation bodies, however most rely on individual landowners and occupiers for protection and management.

2.3.3 The SSSI designation covers important sites for nature conservation of national and international importance and such sites are afforded a measure of protection under the Wildlife and Countryside Act, 1981, against operations which might damage their interest. There are currently about 3750 sites which are designated as SSSI's, covering about 6% of the land surface of Great Britain [(1)], some of which qualify as Special Protection Areas (SPAs) or Ramsar Sites. The notification of SSSIs is a continuing process since some may be denotified due to damage or loss, and other previously unrecognised sites may be discovered, however the number of SSSIs is unlikely to change drastically.

2.3.4 International/European designations which are SSSI include:

- Ramsar sites: wetlands of international importance
- SPAs: Special Protection Areas, designated under EC Directive 79/409/EEC relating to the conservation of wild birds.
- SACs: Special Areas for Conservation to be designated under the EC Habitats and Species Directive (92/43/EEC).

2.3.5 Government policy on planning issues is set out in Planning Policy Guidance notes (PPGs) which provide guidance to local authorities and others on the operation of the planning system. With regard to nature conservation, the main guidance is to be found in PPG1, PPG7 and PPG12. The importance of nature conservation is emphasised in DOE Circular 27/87, however, this will be replaced by an updated PPG later in 1994.

2.3.6 All Local Nature Reserves (LNR's) are owned or controlled by local authorities and some, though not all, are SSSIs. LNRs are protected by planning restrictions in local mineral plans. Nature conservation sites of County Interest, ranked as A, B or C, are non-statutory but are usually protected in some measure by general planning policies, although this can be minimal.

2.3.7 It is important to realise that non-designated areas may have potential nature conservation interest. Whether or not a site is designated is immaterial in some respects, because industry codes regarding environmental practice and good neighbourliness in the community cut across such distinctions.

2.4 The Role of the National Rivers Authority

2.4.1 The National Rivers Authority (NRA) has responsibilities under the Water Resources Act, 1991 for maintaining the integrity of the water environment, and improving it where justifiable, in terms of both quantity and quality. Its roles include the control of water abstractions and effluent discharges by the issue of licences, however Section 29 of the Act specifically excludes dewatering of mineral workings as a licensable abstraction.

2.4.2 The NRA is a statutory consultee in all matters where the water environment is concerned. Of particular relevance to the minerals industry is the NRA's Groundwater Protection Policy B2[(2)] which requires the NRA to object to new mineral workings that will adversely affect water resources unless adequate mitigation is provided.

2.4.3 In addition to the above, the NRA has the power to serve Conservation Notices under Section 30(2) of the Water Resources Act, 1991 on any activity in order to safeguard water resources. Conservation Notices can be used to restrict the pumping from mineral excavations and are likely to be used much more in the future.

2.4.4 The NRA also has a duty, defined in Sections 16 and 17 of the Water Resources Act, 1991, to further nature conservation. The NRA tends to be active where non-designated sites are concerned and to consult closely with EN where SSSI designations are involved. Where development removes water features, a policy of reinstating like for like is generally followed.

2.5 The Minerals Extraction Industry

2.5.1 The United Kingdom possesses a large variety of mineral resources and the extractive industry makes an important contribution to the nations economy. In 1991 over 2650 mineral workings were in operation producing a range of minerals for a large number of applications, although the majority was accounted for by aggregates for use in the construction industry. The chemical industry is another major user[(3)].

2.5.2 Although mineral resources are large they are also finite and minerals extraction policy is controlled at a national level by the Department of the Environment (DoE). Guidance is provided in Minerals Planning Guidance notes (MPGs) and those of particular relevance to nature conservation are MPG1, MPG2 and MPG6. Against a background of continuing demand for mineral, particularly aggregate, the following trends within the industry have been noted:

- a move towards larger, deeper quarries
- a climate of increasing environmental constraint
- fewer greenfield sites obtaining planning consents; with most applications being made for extensions to existing quarries, either laterally or with depth
- a trend to seaborne aggregate originating from coastal superquarries.

2.5.3 In the recent draft revision of MPG 6 (1991) it was stated that Government Policy was to ensure that the construction industry receives a steady and adequate supply of material at the best balance of social, environmental and economic cost. Estimates were made of demands and of mineral reserves in the vicinity of the main demand centres.

2.5.4 The predicted growth in demand for aggregate within the draft MPG6 is considered in some quarters to be unrealistically high, however one of the general conclusions remains; proven reserves in the near proximity to the main demand centres are going to come under increasing pressure in the future.

2.5.5 The current planning climate is moving towards the formation of Development Plans for councils across the country which will set the framework within which planning applications will be decided (PPG12). Development Plans typically comprise:

- Structure Plans, which set out general policies of regions or counties
- Subject Local Plans, which set out more detailed policy on specific matters for a locality, e.g. Somerset Wetlands Local Plan. Local Minerals Plans come into this category.

2.5.6 The presumption will be to favour planning applications which are in line with the Development Plans. Applications which are outside or omitted from the Plans will generally be refused.

2.6 Environmental Assessment

2.6.1 European Directive 85/337/EEC was adopted on 27 June 1985 and was given legal effect through the Town and Country Planning (Assessment of Environmental Effects) Regulations, 1988 (SI No. 1199). This requires environmental assessment to be carried out before development consent is granted for certain types of major project judged to have a likely significant environmental effect.

2.6.2 Environmental assessment (EA) is a systematic and objective method by which information about environmental effects is collected, assessed and used to inform decision making and should be considered as an iterative process. Guidance on the procedures involved is given in the DoE Guidance on Environmental Assessment[4].

2.6.3 Extractive industry is considered a 'Schedule 2' project under the Act and environmental assessment is therefore not mandatory. Much depends on the definition of what constitutes 'significant' in Section 2.6.1 above. DoE Circular 15/88 (Welsh Office Circular 23/88) suggests three main criteria for assessing significance:

- whether the project is more than local importance, principally in terms of physical scale. As an indicative threshold, an area of 50 ha is stated above which sites may well require EA[(4)].
- whether the project is intended for a particularly sensitive location, eg a national park or SSSI, and for that reason may have significant effects on the areas environment, even though the project is not on a major scale.
- whether the project is thought likely to give rise to particularly complex or adverse effects, eg in terms of discharge of pollutants.

2.6.4 Each application will therefore need to be assessed on its merits, however. EA is likely to be required where sensitive areas of nature conservation are involved, (such as SSSIs) or the proposed development is large. Even if EA is not formally required, English Nature consider the methodology to be best practice for assessing the potential impact of mineral working on the hydrology of sensitive nature conservation areas and for providing suitable mitigation. The pertinent features are:

- that assessment is the developer's responsibility
- it is a collaborative exercise with the Planning Authority and Statutory Consultees, with consultations early in the planning process
- assessment is an iterative process continuing through the life of the project with the results allowed to influence the final design
- mitigation works are included, if required.

3.0 THE HYDROLOGICAL CYCLE

3.1 Explanation and Definitions

3.1.1 Water, unlike other mineral resources, is not irreversibly consumed but is recycled through the environment. The hydrological cycle represents the movement of water within the environment, including changes of phase, and is presented pictorially in Figure 1 and as a system in Figure 2. Variations to the cycle are almost limitless, particularly with respect to the zone below ground [5,6].

3.1.2 In the sections which follow, the following definitions are used:

- surface water: water occurring at, or on, the ground surface
- groundwater: water occurring beneath the ground surface; both within the unsaturated zone (above the water table) and within the saturated zone (below the water table)
- catchment: an area in which all water drains to a single point
- water table: (or phreatic surface) the boundary between the unsaturated and saturated zones.

3.1.3 Furthermore, hydrology is used in its literal sense of being the science of water, incorporating both surface water hydrology and groundwater hydrology (or hydrogeology, as it is more often known). Further definitions are found in the glossary at the back of this report.

3.2 Interaction Between Hydrological Processes

3.2.1 It is important to realise that the processes within the hydrological cycle are inter-related and therefore dependent upon each other. The catchment is a natural unit within which to consider the interconnection of hydrological processes and because groundwater and surface water catchments do not always coincide, the relationship may be expressed as the following equation:

$$P = E + S_R + G_R \pm U \pm S$$

where

P = precipitation

E = actual evaporation

S_R = direct run off

G_R = groundwater discharge

U = nett groundwater flow through aquifer

S = change in storage in groundwater

These are shown diagrammatically in Figure 1.

3.2.2 This equation is often termed a water balance and it is often possible to quantify its components in general terms on a catchment-wide, or water resources scale. The difficulty comes in relating a predicted change on the large, water resources scale, to an effect on ecology in the local context.

3.3 Relationship Between Ecology and Hydrology

3.3.1 There are many reasons why a particular species or habitat is present in a particular location, for example the climate, underlying geology and soil, historical land use or existing management practices. However, the local hydrology is a crucial factor. The presence or absence of water at a site and its seasonal variations in terms of levels and flows all combine to determine whether a particular species can adapt to, or continue to be present in a certain area.

3.3.2 Two general points regarding ecology and hydrology can be made:

- different habitats have different water requirements, for example chalk grassland or dry heath needs less water than flood plain meadows
- different species have different tolerances. Dandelion and rye grass, for example, are ecologically very tolerant, whereas Snakes Head Fratillery and Downy Fruited Sedge have a very tightly defined ecological requirement and are extremely sensitive to change.

3.3.3 In most instances the hydrological processes which directly influence the local ecology are those which occur within the unsaturated zone of the soil profile and which therefore fall within the field of soil physics, rather than classical hydrology. In detail the processes are extremely complex but include:

- infiltration: the acceptance and drainage of precipitation or surface water through the soil profile

- capillary rise: the natural movement of water upwards from the water table into the unsaturated zone storage. This varies from between 0.2 - 0.4m in coarse sands and gravels to up to 1.0 - 2.0m in clays(7) and is illustrated in Figure 3.

- evaporation: the movement of water vapour into the atmosphere from the soil profile by direct evaporation and from transpiration of flora; the latter being influenced by the suction that particular root systems can exert to draw water held within soil and storage.

3.3.4 Because of the complexity of these processes it is extremely difficult to relate specific groundwater or surface water level changes to variations in soil moisture. Good documented scientific evidence is scarce. Similarly , relating changes in soil moisture to stress on plants is hindered by the absence of data over an extended period.

3.3.5 Some documentary evidence exists, such as the effect of groundwater level changes beneath Redgrave and Lopham Fen, a Ramsar site in Suffolk, however this tends to concentrate on extreme changes, which obviously cause extreme effects[8]. Little is known about the threshold stress of particular species, although there is the suggestion that some species may be sensitive to water level changes of 50mm[9]; a level of detail which is unlikely to be achieved with predictive model techniques.

3.3.6 Current research has followed two methods of linking hydrology and ecology;

- direct measurement of soil moisture in relation to the water table variation[10]
- statistical correlation of plant distributions and the water table in certain habitats, notably fens in Norfolk and wet grassland in Somerset.

3.3.7 Such significant gaps remain in our understanding, that it is reasonable to assume that processes are unlikely to be defined accurately enough in order to quantify whether particular changes at specific sites are significant or not to the survival of a particular species. There are simply too many variables and too little background life-cycle data available. What is important about the processes described in Section 3.3.3 is to realise that they are occurring, that they may be contributing to the water demand of a species or assemblage, and that they may be influenced by changes to other parts of the hydrological cycle.

3.3.8 Given these uncertainties, can anything useful be said relating hydrology and habitats? The answer is affirmative if general relationships are considered and this is considered to be the most pragmatic way of assessing the potential effects of mineral workings.

3.3.9 Some general habitats are described below:

- dry acid heathland is an example of how some habitats exist on water stored within the top few centimetres of soil, out of 'reach' of the water table. In fact, one of the biggest misunderstandings is of the influence of the water table on ecology. It is entirely possible for many assemblages to exist well out of the influence of the water table and capillary rise[7].

- fen is an example of a habitat which is dependent on the maintenance of a high water table with little natural variation, usually spring fed.

- valley meadows are often characterised by a well defined soil structure with seasonal flooding and the slow infiltration of water, possibly also dependent on a high summer water table. They are a typical example of how little is known about the critical the processes at work in the unsaturated zone with respect to the sensitivity of the assemblages.

3.3.10 The significant gaps in our detailed knowledge are the main reason why English Nature adopt the precautionary approach of assuming that the existing hydrological regime is optimum and should be maintained, in order to protect nature conservation interests. This approach is justified when consideration is given to the apparent sensitivity of some species (Section 3.3.5).

4.0 MINERAL EXTRACTION

4.1 Types of Mineral and Operation

4.1.1 The United Kingdom possesses a large variety of minerals, some of which are extracted for commercial or industrial purposes. Extraction operations, however, fall into two main categories:

- deep mines: where access is from the surface in shafts or drifts. Examples of minerals which are worked by this method are coal, salt and potash.
- surface mineral workings: where the overlying material is removed by opencast excavation.

4.1.2 The sections which follow concentrate on surface mineral workings, where the mineral is extracted directly from the surface after the removal of the overlying material. These form the majority of operations in this country. Peat workings have specifically been excluded (Section 1.3.4).

4.1.3 Opencast operations can be broadly classified by the physical characteristics of the mineral deposit as being soft or hard. the majority of soft rock workings are relatively shallow excavations associated with the production of sand and gravel, mostly for aggregates. Other examples include china clay operations and clay and chalk pits. The size of these workings varies enormously from very small pockets to excavation of large areal extent.

4.1.4 Hard rock quarries tend to be deeper and larger, up to 'Superquarry' scale (eg Glen Sander) and the range of minerals which is excavated includes:

- limestone, dolomite
- sandstones and quartzite
- igneous and metamorphic rocks
- coal and associated cementstones and shales
- slate and marl
- china clay
- barytes, fluorspar
- iron and other metalliferous ores

4.2 Methods of Opencast Extraction

4.2.1 There are two main methods of working minerals opencast:

- dry working: where excavation does not encounter saturated ground, either because it remains above the natural water table level, or because the water table is artificially lowered. The majority of UK operations are worked dry, the benefit in soft deposits being that all the mineral can be extracted.

- wet working: which refers to the extraction of relatively shallow sand and gravel deposits below the water table by draglines, or by dredging from pontoons or barges. Wet working is generally regarded as a less efficient and economical method because of the difficulty in extracting all the available mineral.

4.3 **Control of Water During Extraction Operations**

4.3.1 Quarries have the potential to intercept large volumes of water during extraction from either groundwater or surface water. The volumes which are intercepted can usually be controlled provided that sufficient engineering measures are taken and these are discussed in the following sections.

Groundwater

4.3.2 The volume of groundwater which is intercepted depends on the size of the excavation, its depth below the water table but more importantly on the type of mineral which is being extracted and the surrounding geology (Section 5.1.1). The NRA regard dewatering operations as unlicensed abstractions and Conservation Notices may be served to ensure that water resources considerations are not jeopardised (Section 2.4.3).

4.3.3 In most UK operations, dewatering is achieved by pumping from a sump in the base of the excavations, to which intercepted groundwater may be fed by a system of trenches. Other dewatering methods include[11]:

- pumping lines of interconnecting wellpoints
- horizontal or inclined drains and shafts (or galleries in more complex hydrological environments).

Surface Water

4.3.4 Runoff originating from outside a site is often intercepted by peripheral cut-off ditches and routed around the working to be discharged in a controlled manner downstream of the site. The ditches are usually graded to prevent ponding in water, which is potentially dangerous above a batter slope, and the perimeter may be lined in some cases to prevent erosion or seepage.

4.3.5 Large excavations become catchments in their own right and may therefore collect significant volumes of water after intense rainstorms, especially if the quarry floors are made impermeable by vehicles compacting them. This water will need collecting and discharging, preferably in a controlled manner.

4.3.6 Surface runoff which is generated within the site can cause major erosion of topsoil and overburden stockpiles and batter slopes, causing suspended solids loading in the collected water. Some form of treatment may therefore be required before discharging off-site.

4.4 Water Requirements and Controls

4.4.1 The main requirement for water within a working is usually for washing, although other processes such as concrete mixing may occur. Some form of settlement to remove sediment from the process water is usually required before water originating on-site can be discharged to receiving watercourses.

4.4.2 Consents to discharge should be obtained for all discharges of water, whether clean or contaminated, from the site.

5.0 POTENTIAL EFFECTS OF MINERAL EXTRACTION ON THE HYDROLOGICAL REGIME

5.1 Introduction

5.1.1 Mineral workings, by their very presence, will all affect the hydrological regime in which they occur to some degree. However, schemes vary widely in the scale and nature of the effects they may cause. Some, such as limestone quarries can have large, far-reaching effects on water resources due to the hydrogeological characteristics of the prevailing geology, whereas developments in igneous terrains or clay strata may cause only minor effects. Others, such as gritstone quarries, are intermediate in effect.[12]

5.1.2 All stages of an extraction scheme have the potential to affect the water environment, including the phases of site preparation, operation and restoration. The hydrological effects which need to be assessed for both temporary and permanent works are as follows:

- the effects on water quantity; ie on water levels and flows
- the effects on water quality

5.1.3 These need to be examined in the following contexts:

Local Effects and Regional Effects

5.1.4 Some schemes, due to the nature of the particular site, and its associated topography and hydrogeology, may have effects relatively remote from the origin of the disturbance such as limestone working in the Mendips[2,12]. These need to be considered, as well as more local effects.

Cumulative Effects

5.1.5 Extensions to existing quarries may produce cumulative effects due to a history of successive workings, such as the progressive extraction within the gravel aquifer at Dungeness which has derogated water sources (13).

Long Term Effects

5.1.6 Some effects are gradual and only make their presence known after a number of years. By their nature, these effects are more difficult to predict and can only be verified after long-term monitoring. However, assessing perceived effects over an extended period is often complicated by the absence of good historic baseline information against which to compare monitoring data.

5.1.7 It is important to understand, however, that effects due to mineral working are not only adverse but can be beneficial as well. The purpose of providing mitigation measures within the design of any scheme is to minimise the potentially adverse effects and maximise the potential for enhancement of the scheme.

5.1.8 For ease of reference the following sections are divided between surface water and groundwater effects. However, in many areas of mineral extraction where nature conservation is an important consideration, such as in river valleys, the use of this division is somewhat artificial. Surface water and groundwater interaction is illustrated in Figure 4.

5.2 Factors Affecting Surface Water Quantity

5.2.1 Some watercourses are designated as river SSSIs due to biological or geomorphological features, such as the River Lugg in Herefordshire or reaches of the River Blythe in the West Midlands. Designated watercourses are particularly susceptible to surface water effects, however the following sections may be equally relevant to terrestrial sites which are sensitive to changes in the surface water regime.

Operation

5.2.2 The formation of an excavation often reduces the catchment area of streams and other areas downstream of the area within which the excavation lies. However, during excavation, the component of surface flow can actually increase overall because of:

- discharge of dewatering water to the receiving watercourse
- discharge of drainage collected within the operations (Section 4.4)

Such discharges can affect the natural pattern of flow downstream with consequential effects in fisheries and other aquatic life.

5.2.3 Some excavations in the floodplain, usually for sand and gravel, abstract river water for mineral washing. Such abstractions can also affect downstream flow patterns. If the abstraction is situated upstream of the site and wash water is returned downstream, a reach of lower flow is produced adjacent to the site which can impoverish the watercourse.

5.2.4 Removal or realignment of watercourses as part of the mineral working may also result in a significant loss of aquatic and riparian habitat.

Restoration

5.2.5 Different restoration proposals can cause different effects. The main categories of restoration are discussed below:

- Land raising, particularly with low permeability landfill caps, can increase the proportion and rate of surface runoff, though this can often be infiltrated if required (Section 9.4) or other attenuation measures provided.

- Open-water restoration of workings. In many places where clay is present beneath sand and gravel it is worked into a peripheral seal to mitigate against large drawdowns when working the mineral dry. At restoration, the clay seals hinder the movement of groundwater through the worked area (Figure 7 top), which on a large scale could hinder the baseflow (ie., groundwater) component of watercourses, particularly in dry periods. Surface water collecting in the isolated clay 'dishes' often rises above the regional water table, requiring control of water levels.

- Low level restoration has been suggested as a means of returning land to agricultural use where mineral has been extracted below the water table (14). It would often utilise the clay seals described above as a means of limiting groundwater seepage into the restoration, however any seepage or surface water entering the area would need to be removed by pumping. The comments made above regarding baseflow to adjacent watercourses therefore also apply. However, low level restored sites can also be used to provide significant flood attenuation if water is allowed to collect. The rate at which water is pumped from the excavations, however, would be critical (14) and operational problems could occur if permanent pumping on a large scale was initiated, as has been proposed in Phase 2 of the Cotswold Water Park.

5.3 Factors Affecting Surface Water Quality

Physical Contamination

5.3.1 Physical contamination through suspended solids loading is probably the greatest potential water quality problem in the mineral extraction industry and can occur through all phases of operations. It is of particular concern in that many sand and gravel operations directly overly clay deposits which can introduce a high amount of colloidal material into the surface water system during washing or dewatering operations. The problem is of relevance in nature conservation terms because some species are extremely sensitive to colloidal material (eg *Sphagnum sp.*).

Chemical Contamination

5.3.2 Chemical contamination can occur through a variety of means, some of which are listed below:

- discharge of dewatering water if chemically incompatible with the receiving water
- oil and solvents from plant and coating works
- wash water contaminated by processing, eg concrete mixing
- fertilisers or pesticides used on screening bunds or the restored landform
- rainwater leaching minerals or metals from spoil tips, eg in stockpiled coal measures
- wash water from an incompatible source eg chalk mains water in an area of acid heathland.

All discharges, however, are subjected to licensing by the NRA.

5.4 **Factors Affecting Groundwater Quantity**

Operation

5.4.1 The most important factor to be considered during mineral extraction is whether or not dewatering is required. If wet working is viable (in sand and gravel) the effect on water flows and levels will be considerably less than if dewatering is necessary.

5.4.2 Dewatering causes a depression in the water table (or the piezometric surface where the water is pressurised), which is greatest in the vicinity of the excavation and decreases progressively away from it (Figure 5). The amount of the depression at any point is dependent on the structure and permeability of the mineral deposit, the depth of the excavation in relation to the phreatic or piezometric surface, the distance from the excavation and the amount of water being pumped. It is important to realise, that often the type of mineral which is extracted, and the surrounding geology, determine the scale of the hydrological effects which are experienced (Section 5.1.1).

5.4.3 Dewatering operations can affect adjacent areas by:

- reducing the water level in ponds
- reducing the amount of water available in the soil, either directly or indirectly by reducing the effect of capillary rise (Figure 3)
- reducing the volume of groundwater flowing through an area
- reducing stream flows or levels, spring discharges
- induce saline water near coasts to flow inland with adverse implications to freshwater flora and fauna if discharged to watercourses

These all have the potential to influence nature conservation areas and are illustrated in Figure 5.

5.4.4 In some areas, such as the Cotswold Water Park, clay beneath the mineral deposits is used as a lateral seal to limit the area which is affected by dewatering, however this changes the local aquifer characteristics. The clay acts to reduce the overall permeability, reducing groundwter throughflows, however, storage tends to increase as the mineral volume is replaced by water. Whether these changes are significant or not depends on the scale of the working in relation to the regional situation. (See Section 5.4.5 below).

5.4.5 Where excavation is carried out above the water table, groundwater flows are affected by the removal of the unsaturated zone which controls the rate of infiltrating recharge to the saturated zone by holding it in temporary storage. The unsaturated zone is often significant in damping the response of receiving springs and streams to recharge events by the slow release of water to the saturated zone. In karstic (limestone) aquifers it is a very important mechanism for maintaining summer baseflows and attenuating winter peak flows [15]. The removal of temporary storage therefore tends to make the response of surface flows more extreme, by increasing winter flows and decreasing summer flows, the effect depending on the characteristics of the aquifer and the amount which is removed. It can be made good by the adoption of suitable mitigation measures, one of which is described in Section 9.6.3.

Restoration

5.4.6 All development has the potential to affect the amount of infiltration to groundwater and some of these effects are illustrated in Figure 6. High level restoration is often favoured by mineral extractors as a means of reproducing original ground contours. Landfilling policy favours contained sites with low permeability caps which tend to reduce the amount of recharge to the surrounding strata by encouraging water to runoff, rather than to infiltrate. The effect is generally negligible where the size of the landfill is small in relation to the groundwater catchment, as for example, in many flood plain situations. The effects can be quite marked, however, where the landfill area comprises a significant proportion of the groundwater catchment to an adjacent conservation area, particularly if the original formations were highly permeable. Infiltration of the surface runoff can quite easily restore this balance and is often regarded favourably in land drainage terms by the National Rivers Authority (see Section 9.6).

5.4.7 Where landfilling is within the saturated zone, the groundwater profile has to reconfigure because of the reduced flow pathways, leading to higher groundwater levels upstream and lower levels downstream. A similar effect is caused when working is carried out inside a peripheral clay seal (Section 5.4.4)[16]. The effect is shown in Figure 7.

5.4.8 The introduction of permanent surface water features within the mineral working has the potential for great environmental enhancement as dewatering finishes and groundwater levels are allowed to recover to equilibrium, although the formation of lakes can also lead to higher evaporative losses.

5.4.9 A study into falling groundwater levels and rising salinity in the coastal gravel aquifer at Dungeness [13] concluded that mineral extraction leading to removal of the aquifer and higher evaporative losses was partly to blame, although over abstraction was the major cause. In many other instances, however, water levels in abandoned sand and gravel workings have risen slightly with time, which is usually attributed to silting of the lake beds or the fact that the lake now receives 100% recharge [16]. This is a good example of how each situation must be considered on its own merits.

5.4.10 The scale of the water feature must also be considered as lakes tend to flatten the water table. Where large lakes are arranged perpendicular to the groundwater gradient, lake levels tend to be lower than the original groundwater levels upstream and higher downstream, with serious implications for sensitive flora and fauna in close proximity (Figure 7).

5.4.11 It is important to realise, therefore, that whatever method of restoration is used, the water table never reconfigures exactly. Figures 8 and 9 illustrate two examples regarding springs. In Figure 8 the formation of a large lake in a subwater table quarry dries a spring because the original sloping water table is removed. In Figure 9 springs emerge because quarrying intersects two discrete water-bearing horizons which combine to produce a common water table on infilling.

5.5 Factors Affecting Groundwater Quality

Physical Contamination

5.5.1 Groundwater contamination by sediment is not usually considered in granular aquifers because of the natural filtering effect of the ground, however a number of springs in the Mendips utilised for water supply have been abandoned in the past because of contamination by suspended solids from active quarries, such as St Dunstan's Well and Holwell Spring [12, 15]. Contamination was made possible by the high secondary permeability of fissures within the limestones and poor operational control.

Chemical Contamination

5.5.2 As with suspended solids, groundwater is generally regarded as being less susceptible to chemical contamination because of the 'cleansing effect' that microbial processes have within the unsaturated zone. However, all the factors mentioned in Section 5.3.2 also have the potential to affect groundwater quality, particularly in karstic limestones. A recurring problem at present is the presence of diesel fuel within the Speedwell Cave system, part of the Castleton Caves SSSI in Derbyshire. This is believed to be caused by leakage from unbunded diesel tanks in operational quarries. However, poorly mixed ammonium nitrate and fuel oil, used within blast holes, may also be to blame (P Hardwick, University of Huddersfield, pers. comm.).

5.5.3 In addition to these, and possibly of greater concern, is leachate from landfill sites, which if allowed to escape, can have a catastrophic effect on both groundwater resources and nature conservation interests.

5.6 Regional and Cumulative Effects

5.6.1 The large majority of operations are relatively small and are unlikely to have any effect on the regional hydrology. However, large scale operations or the cumulative effects of progressive development can be significant. The critical factors are again the local hydrology, the mineral being extracted and the methods being employed. Selected examples from case studies illustrate the wide variety of regional effects that can be experienced:

- Activities at Whatley Quarry, within Carboniferous Limestone in the Mendips, have been shown to affect the Oldford borehole 6km away[(2)].

- Piecemeal development of gravel extraction within the Cotswold Water Park in Gloucestershire has caused a reduction in flows in the upper reaches of the River Thames by effectively redirecting groundwater baseflow as surface drainage to a point lower down the river[(17)]. Studies on the Lower Colne Valley near London similarly concluded that the large number of worked out pits had significantly affected the natural drainage of the area[(18)].

5.6.2 Many discrete aquifers have been interconnected by tunnels, drifts and shafts in the majority of British Coalfields, together with the worked seams, often causing major changes to the regional groundwater configuration. Huge volumes of water are now held in storage, in a maze of interconnected passageways which act as a 'man-made' form of high secondary permeability.

5.6.3 This can be of importance when opencast operations rework previously deep-mined coal. Not only can there be rapid inflow from rainfall through the interconnected passageways but vast quantities of water may need to be dewatered which can have unexpected results some distance away, with implications for nature conservation.

CASE STUDY : MOORCROFTS POOL, WALSALL, STAFFORDSHIRE

Moorcrofts Pool is a shallow man-made lake that formed due to a combination of sand extraction and mining subsidence from shallow, underground coal workings. When opencast coal extraction commenced at the Paydon Shaft site in neighbouring Sandwell, where the coal is at outcrop, a large volume of groundwater was encountered. As dewatering progressed, water levels in Moorcrofts Pool 3km away began to fall and it eventually dried, although this coincided with an extremely dry summer period.

The hydrology of the area is complex and poorly understood in detail. It is possible that advanced dewatering caused the lake to dry if hydraulic continuity existed between the worked seams and the overlying glacial drift, although this has not been proven. However a buried glacial channel about 9m deep, known as the Moxley Drift Channel, occurs between the two sites.

5.7 Summary of Hydrological Effects

5.7.1 A summary of the main effects is given in the following tables which are reproduced within the Guidelines. It is important to be aware of the range of effects that can occur but it should be emphasised that these tables are only a guide and should not be used as a comprehensive checklist of all the possible effects at all sites.

5.7.2 Equally, it should not be assumed that these effects will always be found at every site. Many effects will not occur or will be mitigated by good practice. In this respect each site should always be considered in its own context.

Table 5.1

SURFACE WATER EFFECTS	PHASE: SITE OPERATION
<u>Quantity</u> • Loss of surface catchment (hence reductions in flow downstream) • Removal or realignment of watercourses • Changes in pattern of downstream flows due to abstractions or discharges from the site (eg dewatering water, process water, on-site drainage) • Interception of surface runoff (hence reductions in overland flow downslope of the site)	
<u>Quality</u> Poor water quality discharges from the site including contamination by: • Suspended solids loading • Oil and solvents • Process wash water • Leaching from spoil tips (eg in stockpiled coal tips) • Dewatering water which is incompatible in quality with the receiving watercourse	

Table 5.2

SURFACE WATER EFFECTS	PHASE: RESTORATION AND AFTERCARE
<u>Quantity</u> • Increased runoff from raised landform, particularly with low permeability caps on landfill • Permanent alteration of downstream surface flows due to low level restoration (a flood storage effect) • Reduction in baseflow to adjacent watercourses due to the blocking off of groundwater by clay sealing • Increased evaporation from open water restoration and storage of rainwater	
<u>Quality</u> • Fertilisers or pesticides from restored grassland • Leachate from restored landfill • Algal blooms in restored lakes - transfered to watercourses	

Table 5.3

GROUNDWATER EFFECTS	PHASE: SITE OPERATION
Quantity Dewatering can cause lower groundwater levels around the site which may result in a reduction in the following: • Levels of ponds • Flow from springs and seeps • Stream flows and levels • Available soil water • Levels in boreholes and borehole yields • Groundwater flow through an area, and • Intrusion of saline water from estuaries or the sea There can also be reduction in aquifer recharge due to blockage of porous ground by silt The physical removal of aquifer material can alter the rate of recharge to springs and streams making their response to rainfall or lack of rainfall more extreme.	
Quality Effects include: • In fissured rocks (e.g.limestones), contamination of spring sources by sediment • Chemical contamination by oils and solvents, leachates or soiled wash water • Loss of dilution due to reductions in groundwater flow	

Table 5.4

GROUNDWATER EFFECTS	PHASE: RESTORATION AND AFTERCARE
Quantity Effects once restoration has been completed can include: • Impedance or cutoff of groundwater flow due to presence of sealed landfill in the saturated zone resulting in changes in groundwater levels and flow direction. • Loss of recharge due to impermeable capping on landfill (likely only to be significant as a localised effect) • Physical loss of aquifer material can alter groundwater levels which may also affect adjacent streams • Increased evaporation losses where sites have been restored to open water • The local "flattening" of groundwater gradients by the presence of lake features	
Quality • Chemical contamination from leachates	

6.0 UNDERSTANDING THE EXISTING HYDROLOGICAL REGIME

6.1 Introduction

6.1.1 Where there is a perceived risk to an area of nature conservation interest, the site hydrology will nearly always be a planning issue requiring some form of hydrological assessment, whether or not a full environmental assessment is required. The aim of this section is to provide a practical summary of the factors which should be considered during the planning process in order to assess the hydrological regime. Where an environmental statement is required for mineral planning applications attention should be drawn to the DoE Guidance(4,19).

6.1.2 Two general points of importance should be addressed at the outset of the scheme:

- early consultation with the statutory authorities as emphasised by DoE Circular 15/88 for environmental assessments

- consideration of the application area within the overall hydrological framework. Some schemes are delayed at planning stage because they treat the application area in isolation from its surroundings.

6.1.3 The above issues are related in that the statutory consultees are best able to give an appreciation of the regional environment and concerns. Early consultation will enable an initial risk appraisal to be performed relatively quickly at the beginning of the planning process. The value of the nature conservation site can be stated and areas of concern within the development proposal highlighted, enabling the overall requirements of the hydrological assessment to be scoped. Taken together, these measures should prevent unnecessary delays or duplication in work.

6.2 Extent of Hydrological Assessment

6.2.1 The extent of the assessment will vary from application to application and should reflect the nature and scale of the extraction which is proposed. The key factors which will influence its scope are:

- the size of the development in relation to the nature conservation area(s)
- the proximity of the development to the nature conservation area(s)
- the complexity of the hydrological processes which are operating
- the value of the nature conservation site(s)

6.3 The Need for Data in Assessing Baseline Hydrological Studies

6.3.1 The problem of variability in the natural environment is especially true of hydrological parameters, which vary in both time and space. Data are therefore critical in understanding the hydrological processes which are operating and their interaction. Early consultation with the NRA is beneficial in that it highlights what information is already available, both from historic archived data and ongoing monitoring programmes[19].

6.3.2 It is likely, however, that monitoring programmes will need to be initiated to augment the existing information. The spatial coverage and frequency of data collection will again be influenced by the factors given in Section 6.2 above, however, there is the possibility that very detailed information over time could be required. Monitoring networks should therefore be designed for obtaining data prior to the application, as part of the initial site appraisal, and throughout the period of extraction and afteruse.

6.3.3 Information on the following could be required:

- surface water flows and levels
- groundwater flows and levels
- surface and groundwater catchment areas
- water chemistry
- meteorology
- soils and soil water
- water tracing in karstic areas

6.3.4 Not all the above may be necessary or relevant to a particular location. In most cases the variation in surface water and groundwater will be the critical requirements. In general, the minimum length of data record which is required will be one year allowing an assessment of a hydrological 'high' and 'low' to be made. Longer periods may be necessary, however, particularly in complex or sensitive areas, or where data are judged to be atypical due to extreme climatic conditions.

6.3.5 Data should never be collected for their own sake and for this reason monitoring programmes should always be directly related to the development proposal and subject to review (Section 8.5). Adverse circumstances may occur which prevent investigation or monitoring outside the development area, however, it should be recognised that hydrological monitoring relating to the area of nature conservation interest is likely to be required.

6.4 Surface Water Processes and Monitoring

6.4.1 Flows generated from incident rainfall within a mineral working, as well as those intercepted by peripheral drainage ditches should be quantified as part of current best practice in mineral applications as well as for obtaining the necessary NRA Consents for disposal off site (see Section 9.9.1). These require an assessment of the undeveloped situation within the application area. A good summary of the procedures is given in the DoE review of the stability and hydrogeology of mineral working [11].

6.4.2 The use of the same methods should be extended to incorporate the nature conservation area.

6.4.3 In addition, the main surface water features which are considered to fall within the perceived 'risk zone' of the working should be monitored, particularly those within the nature conservation area. These include:

- streams whether those requiring diversion by the proposal, or inflows or outflows from the sensitive area
- springs
- lake or pond levels
- water chemistry

6.4.4 The measurement of spring and stream flows should be to an approved methodology[20]. The frequency of monitoring should be at least monthly over the initial 12 months, but where complex situations or where a rapid response to rainfall occurs, the frequency could be much greater. The use of dataloggers for continuous records should also be considered.

6.5 Groundwater Processes and Monitoring

6.5.1 The DoE strongly recommended that groundwater investigations should always be considered at the design stage of a new quarry or mine[11]. This is of importance because some form of ground investigation is usually necessary and in many cases prospecting boreholes can be utilised for groundwater monitoring.

6.5.2 Usually, boreholes within at least part of the nature conservation area will also be required. Whilst this is not always feasible, where land ownership permits, monitoring boreholes can often be installed easily without damaging the area as long as the appropriate techniques and care are used.

6.5.3 The following information is of relevance:

- piezometric levels and gradients to determine the hydraulic relationships between different aquifers and surface water features
- permeabilities from borehole tests(21); in highly permeable formations pump testing could be required(22)
- groundwater chemistry
- seepages into works and pumped discharges where extensions are sought to existing workings.

6.5.4 As with surface water, much of this information should be obtained for the application area as part of current best practice, for example for establishing safe working and sizing dewatering pumps(11). The coverage of information needs to be extended outside the site into the area of nature conservation interest.

6.5.5 Of particular importance is establishing the relationship between surface water and groundwater processes. In this respect, if extensions are being sought, the monitoring of groundwater levels during extraction phases is essential, as the effects of dewatering extend into adjacent areas.

6.6 Other Monitoring Information

6.6.1 Other hydrological variables which could be required include:

- rainfall
- evapotranspiration

These could be necessary for example if correlation of spring flows with incident rainfall was required, although in the majority of cases this information will be readily available from the Meteorological Office.

6.6.2 Subjective hydrological information of relevance to a project may be available from local residents or users of the locality. Those who are used to observing the natural environment, such as fishermen, farmers or birdwatchers can often provide a useful historical background to the levels of ponds and streams etc.

6.6.3 Ecological surveying provides a measure of detail about natural soil-water conditions which have a bearing on the general habitats which are present (Section 3.3.10). For example the presence of *Sphagnum sp.* means that groundwater is generally at or near the ground surface. In some cases and understanding of soil water variation is available, by the presence of particular species. For example, the presence of Snakes Head Fratillery (Section 3.3.2) indicates very small soil water variations.

6.6.4 However ecological monitoring by itself is insufficient because so little is known about tolerances of particular species (Section 3.3).

6.7 Use of Hydrological Data

6.7.1 Usually, the monitoring data will be assessed by a specialist hydrologist or hydrogeologist with the aims of:

- determining the inter-relation of the hydrological processes which are operating in the area of hydrological assessment, with a view to,
- quantifying the approximate volumes of water which contribute to the various processes.

6.7.2 Whilst the latter is not always possible owing to the variation of the natural environment and the inherent uncertainties which exist, a water balance for an operation should always be the end product to which best practice is aimed. (Section 3.2).

6.7.3 Once the existing hydrological regime is understood the monitoring data will also be used in the assessment of the effects of the extraction proposals (see Section 7.1) and in the design of potential mitigation measures.

7.0 ASSESSING THE EFFECT OF THE PROPOSED DEVELOPMENT

7.1 Introduction

7.1.1 The effects of a proposal can only be assessed if the natural baseline situation and the inter-relationship of the hydrological processes which contribute to it are correctly understood. Where these are known and the hydrological effects are correctly assessed, the results have to be translated into the significance for the site or area of nature conservation under consideration which is itself a function of its value and vulnerability to hydrological change.

7.1.2 Whilst there may be a general understanding of the sensitivity or tolerance of a species or typical assemblage to water requirements for the vast majority of indigenous plant species, little or no data are available relating plant vulnerability to hydrological change (Section 3.3).

7.1.3 Under these circumstances within a very imprecise area of knowledge it is assumed wrongly, or rightly, that the prevailing hydrological conditions are optimal and that gross changes (ie those outside the natural variation) should be avoided.

7.1.4 It is therefore proposed that a very simple approach to classifying hydrological change to areas of nature conservation is adopted as follows:

- those schemes which **definitely will** cause an effect
- those schemes which **will not** cause an effect
- those schemes which **may** cause an effect.

7.2 Assessing Hydrological Effects

7.2.1 The following methods may be of relevance in assessing which of the above categories a particular scheme comes within:

- consideration of the changes to surface and groundwater catchments
- field trials and/or previous experience of working an area
- simulation techniques

7.2.2 The first method will be that most commonly used. The natural surface water and groundwater catchments to an operation and an adjacent site of nature conservation should be defined (Section 6). Consideration of if and how the catchments change during mineral working will indicate much about whether significant changes are likely.

7.2.3 Previous experience of working in a particular area is of great value but is subjective unless it is substantiated by monitoring data which can be extrapolated to the application area with confidence. Working an adjacent area and monitoring, for example, the spread of dewatering with extraction can constitute a field trial and may provide sufficient justification that mineral extraction will not affect an adjacent site of nature conservation importance. An example of such a field trial is given in the case history of Povington and Grange Heath SSSI, (Section 9.5).

7.2.4 Simulating the hydrology by computer modelling can be very useful if there sufficient good quality data against which to calibrate the models and where the flow processes which are involved are sufficiently understood. Where these are known within a reasonable margin of error, simulation can be of high value in assessing how best to operate a site to cause the minimum disruption e.g. Pixey and Yarnton Mead SSSI[23]. On a regional scale such techniques can be extremely useful as a management/planning tool. However, where calibration data are insufficient, either in quantity or quality, simulation is of limited use.

7.3 <u>**Summary**</u>

7.3.1 In summary, in most cases where there is good background data the effects of a development can be assessed to a reasonable degree of certainty in water resource terms. The acceptable error on the results, however could easily be greater than the level of accuracy which could be significant in ecological terms (Section 3.3.4). Therefore unless assessments can show categorically that there will be no effect, a measure of doubt will always remain about the possible effects on ecology.

8.0 MITIGATION

8.1 Philosophy

8.1.1 Some extraction proposals will effect the hydrology of adjacent, or nearby areas, in a manner which will be harmful to nature conservation interests unless specific measures are taken to prevent a detrimental effect. The philosophy behind mitigation is to maintain the hydrological "status-quo" in order that mineral working may progress, ensuring that no detrimental effect is caused either in the short or long term.

8.1.2 Mitigation measures can be divided broadly as follows:

- temporary measures: to accommodate temporary effects during all or part of the site working, including restoration. Most schemes will fall into this category.

- permanent measures: to mitigate permanent effects. This can be further divided into those schemes which do not require maintenance and/or plant, and those which do.

8.1.3 Generally, the object should be to interfere with the natural hydrological processes as little as possible, and for this reason temporary schemes are preferred. The finite timescales involved also mean that there is less opportunity for things to go wrong.

8.1.4 Permanent measures are appropriate where aquifer is permanently removed, or where water tables are permanently lowered. Such schemes should aim to mimic the natural hydrological processes in as simple a manner as possible and be sustainable. In some cases there will be an opportunity to use necessary permanent mitigation for long-term benefit. However, any permanent solution should be self-sustaining. Schemes which require a high degree of maintenance or plant, such as continual pumping to maintain spring or stream flows, are vulnerable to neglect and failure and hence loss of mitigation benefit.

8.2 Baseline: Understanding the Local Hydrological Regime

8.2.1 The baseline for mitigation is understanding the local hydrological regime of the mineral development in relation to its surroundings. This includes the areas of mineral working and nature conservation as well as any areas of intervening land. The presupposition is that a hydrological study and assessment has been carried out and that the inter-related hydrological processes are known; mitigation can only be undertaken with confidence if the processes are sufficiently well understood.

8.2.2 Usually, the assessment will be undertaken by specialist hydrologists/hydrogeologists in consultation with ecologists as described in Section 6. The particular mitigation scheme which is proposed should follow from the results of the assessment and should reflect the perceived risk, considered by:

- the size and proximity of the proposed development
- the hydrological processes at work
- the value of the nature conservation site and its sensitivity to hydrological change
- the timescale over which the mitigation is required.

Obviously, the greater the perceived risk, the greater will be the need for sound mitigation measures and control.

8.3 The Place of Field Trials in Mitigation

8.3.1 Mitigation should be seen as an integral part of the design and planning of a mineral working. The critical consideration is whether the mitigation which is proposed can adequately safeguard the interest. For this reason there should be confidence in a particular mitigation scheme before it is initiated.

8.3.2 There are two aspects which should be considered:

- Relevance: there should be confidence that the mitigation scheme is relevant and that it is a practical solution which will work.

- Operational control: every mitigation scheme has itself the potential to cause side effects which can be harmful. For this reason there should be confidence that there is adequate control of the specific mitigation measures which are being proposed. This can only be carried out by analysis of good background data.

8.3.3 Taken together these two factors mean that in many cases field trials will be beneficial. In some cases the field trial could already be operational where there is an existing working which is seeking an extension (see the case study of Wollaston Meadows SSSI, Northamptonshire). In other situations field trials may be necessary to give the Planning Authorities confidence that working may proceed as in the case of the infiltration lagoons which were rested as part of the extension application to Squirrel Cottage ball clay quarry (see case study on Povington and Grange Heath SSSI, Dorset).

8.4 **Is Mitigation Always Desirable?**

8.4.1 In most situations the hydrological processes which are involved can be reasonably interpreted before working begins to enable the effects to be assessed and specific mitigation to be proposed. There is always the possibility, however, especially when dealing with underground strata, that some effects will occur during working which could not reasonably have been foreseen, even with a considerable amount of hydrological data. Nevertheless, even in these situations, some form of mitigation can often be achieved.

8.4.2 Some effects of mineral working will be permanent and of regional importance (see Section 5.4.9) and where these prejudice water resources NRA policy will demand mitigation of water resources. Such changes could obviously be detrimental to sites of nature conservation unless mitigation can be achieved. The important question in such instances is whether mitigation is desirable, particularly if it has to be maintained artificially. Experience suggests that are artificially managed hydrological system cannot fully replicate the semi-natural regime which it replaces in the long-term. This was the view upheld by the Inspector at the Public Enquiry at Morton Pool SSSI, Shropshire[(24)].

8.4.3 Where nature conservation sites are of extreme value in national or international terms mitigation may be undesirable because of the inherent risks and significant questions should be posed as to whether development should be allowed to proceed. In other cases, however, the effects of mineral working can be mitigated by simple engineering measures in conjunction with good management and operational control.

8.5 **The Role of Monitoring in Mitigation**

8.5.1 The place of monitoring in defining natural background conditions (ie before mineral extraction commences) has been described in Section 6. The extent of the background hydrological and ecological data record should reflect the sensitivity of the nature conservation site and the perceived risk of the extraction proposals. This section deals with monitoring during and after extraction.

8.5.2 Hydrological variables, such as groundwater levels or stream flows, can be expected to react more quickly to mineral extraction than ecological indicators. They should therefore be used in relation to the background data as a management tool to assess:

- if mitigation is required
- whether the mitigation is working as envisaged and is sufficient
- controlling the level of mitigation
- when mitigation can be terminated.

8.5.3 The emphasis of monitoring should be to obtain the information that is necessary to assess hydrological effects and mitigation adequately. Monitoring programmes should therefore be tailored to the needs of the specific site and the data which are collected should be subject to regular review. The data review could be submitted to the Planning Authority and/or English Nature, if required. Even if mitigation is never initiated the collection of such data is particularly beneficial to developers if future extensions to the working area are a possibility. Most importantly, the monitoring programme should have an inherent flexibility to allow for example, more frequent reviews, on the basis of the monitoring so far or any other changing circumstance.

8.5.4 The general scope of a monitoring programme where mitigation is anticipated is likely to be the subject of a Condition to the Planning Application. The content of the Condition will be site specific but is likely to link the monitoring programme with the mitigation by a series of agreed procedures, to be implemented if predefined 'trigger' levels are exceeded. Trigger levels should be defined in relation to the background hydrological data and will probably be set at the highest or lowest values as recorded at a number of locations. In some cases they can be seasonally based, as considered, for example, at Farnham Mires SSSI, North Yorkshire. Trigger levels should themselves be subject to periodic review based on the results of monitoring.

8.5.5 An example of a series of actions to be taken once trigger levels are exceeded is given below:

- check data in the field
- inform Planning Authority, NRA and English Nature
- increase frequency of monitoring, eg from monthly to fortnightly
- consult with Planning Authority, NRA and English Nature
- agree hydrological effects and remedial measures to be adopted including a timescale for implementation (a typical timescale would be to implement the remediation within 3 months of the trigger levels being exceeded, although in some sensitive locations response times may need to be much faster.)
- instigate and carry out remediation within the agreed timescale
- review effectiveness of mitigation and report back to Planning Authority, NRA and English Nature eg on a quarterly basis.

8.5.6 Once mitigation is instigated monitoring is critical in assessing and controlling its effectiveness. In the case of recharging water (Section 9), monitoring will determine whether too much or too little water is being utilised and whether additional or less mitigation, or, for example, maintenance of a recharge trench, is required.

8.5.7 In some cases, if the site is considered to be sufficiently sensitive, or at risk, the agreed monitoring and mitigation procedures may become the subject of a legal agreement, such as described in Section 106 (Town and Country Planning Act), 1990.

9.0 POTENTIAL MITIGATION METHODS

9.1 Introduction

9.1.1 This section highlights the potential solutions for mitigating those effects which were described in Section 5 and gives illustrations from relevant case studies where similar solutions have been applied in working extractions. Particular attention is paid to the recharge of quarry dewatering water to mitigate the temporary effects of drawdown which is perceived to be the greatest single threat to hydrologically sensitive areas of nature conservation interest. Recharge is seen as the most practical solution for protecting this resource in the majority of circumstances.

9.2 Planning Considerations to Minimise the Effect on Groundwater

9.2.1 A number of simple measures are available for reducing the effect of a working on the groundwater regime of an adjacent area of nature conservation interest. They are not strictly mitigation, in that they do not prevent effects outside the working area. They are included below for completeness, however, because they have the potential to help safeguard sensitive areas, particularly if considered as one component within a mitigation scheme.

9.2.2 The following are not necessarily always applicable or appropriate to a particular scheme, for example their use may be prevented by other planning or operational considerations. For this reason they should always be considered on a site-specific basis.

Choice

9.2.3 Choosing to work outside the zone of influence of the site of nature conservation importance.

Stand off

9.2.4 If dry working involving dewatering is proposed, leaving an unworked margin will reduce the drawdown effect which is experienced outside the site. This may be applicable where the water table is near the ground surface and relatively small reductions in groundwater level would be serious. It becomes less relevant where the strata are highly permeable because of the shallowness of the cone of depression away from the working (Figure 5) and has the obvious disadvantage of sterilising the available reserve.

Depth

9.2.4 Limiting the excavation depth will also reduce the amount of dewatering, with the consequent advantage to groundwater resources and spring baseflows. This is less relevant to shallow workings where the depth of mineral is critical to the economics viability of the scheme and is more applicable to deep, hard rock excavations, particularly limestone, where discrete levels of extremely high permeability may be present.

Phasing

9.2.5 Alternative phasing of the workings can also be beneficial, for example by minimising the width of working area which is adjacent to the site boundary at any one time. The direction of working can also be advantageous; one aspect being that working towards a site of nature conservation interest, rather than away from it, could allow additional time for monitoring data to be collected and assessed in order to allow the groundwater characteristics of a site to be more fully appreciated.

9.3 **Operational Considerations for Minimising the Effect on Groundwater**

9.3.1 The following methods of operation are intermediate between the above and full-scale mitigation, however they have the potential to be of significant benefit in minimising the effect on the local groundwater environment if applicable to a given situation.

Size of Working area

9.3.2 Minimising the plan area of active mineral extraction by working in small pockets or cells can be highly beneficial in very permeable strata which are being worked dry. It is of particular relevance, for example in sand and gravel or relatively shallow opencast schemes which are being progressively restored, either with previously stripped overburden or imported fill.

Method of Working

9.3.3 In some situations, particularly relatively shallow sand and gravel schemes, working the reserve wet may be more acceptable in terms of environmental impact than working dry, for example at Fray's Farm Meadows SSSI, Greater London. Significant advances have been made in this respect over the last decade or so, although there may be financial implications, for example, in the cost of plant if an extension is being sought to an area currently being worked dry, or if the mineral can only be partially recovered. It also may hinder restoration. Wet working is obviously not applicable in hard rock situations.

Inhibiting Groundwater Ingress by the Use of Cut off Walls

9.3.4 In the past, vertical cut off walls, very similar to those often used beneath embankment dams have been used to inhibit groundwater ingress into sand and gravel workings, usually formed from clay occurring beneath the mineral. These were sometimes situated just along one side of a working, for example where it was in hydraulic continuity with a watercourse and occasionally completely enclosed an extraction area. More recently, where clay is in plentiful supply, it has been used to form peripheral bunds or has been laid as a sheet at an angle so as to form a sealed dish in which dry working can occur. This method of working has been commonly used within the Cotswold Water Park. (Figure 10).

9.3.5 Sheet piling, jet grouting or slurry trenches as used in engineering works are analogous methods which create a barrier to groundwater movement but are generally not practical options because of the extremely high costs involved.

Partial Exclusion of Groundwater

9.3.6 In some cases, the use of a geotextile at the base of a batter slope, generally for stability purposes, has been shown to have been successful in reducing groundwater ingress into a working, causing a corresponding partial recovery of groundwater levels outside the extraction area. Clay or other less permeable fill such as silt arisings is also often used. These methods have been specified as remedial measures in the past, and under some circumstances, could in themselves provide sufficient mitigation to maintain groundwater levels in adjacent sensitive areas. (Figure 10).

CASE STUDY: PIKE CORNER SSSI, WILTSHIRE

The SSSI is an unimproved meadow situated on the southern margin of the Cotswold Water Park, between old gravel workings (now filled with water) and the Swill Brook. It has slightly undulating topography and contains two main assemblages :

- *chalk grassland type, used to well drained soils as on downland*
- *meadow type, requiring high saturated conditions eg. Marsh Orchid, Marsh Pennywart, Parsley Water Dropwart, Slender Spikerush, Flat Sedge.*

Concern was shown that a proposal for dry working of mineral on the eastern boundary of the SSSI could damage the SSSI by unacceptable variation of natural groundwater levels.

The Planning Application was eventually accepted with the following mitigation provisos which are summarised in Figure 11.

- *a series of silt lagoons to be located between the eastern margin of the SSSI and the excavation, to be in place prior to working. These would eventually become a lower permeability barrier to water from the meadow*

- *a clay bund to be located on the northern margin of the working to hinder water ingress from disused workings*

- *dry working from east to west towards the SSSI, with monitoring of the drawdown effect during working*

- *an agreement to change to wet working if a 'detrimental' effect were to be observed adjacent to the SSSI: to be assessed in relation to the background data.*

  Because of land ownership problems no monitoring of groundwater levels was possible in the SSSI. However, fortnightly readings have been taken across the extraction area for over 12 months and will continue during the working period.

9.4 Recharge of Quarry Dewatering Water to Maintain Groundwater Levels

Introduction

9.4.1 Arguably the simplest and most effective means of mitigating reductions in ground water level outside a mineral excavation is by wise use of the dewatering water. In many cases, concerns about the potential effect of dewatering during extraction can be allayed by simple infiltration schemes with good operational control.

Artificial Recharge

9.4.2 Considerable work has been undertaken worldwide on the use of infiltration, or artificial recharge as it is sometimes called, as a means of maintaining and protecting groundwater resources[25,26]. Applications include:

- utilising natural aquifer storage as a reservoir for excess winter water which can then be extracted in summer
- protecting coastal aquifers from saline intrusion by the formation of a hydraulic barrier or mound
- replenishing natural recharge intercepted by a development on an aquifer such as a road or housing estate.

9.4.3 Water can be infiltrated by any of the following methods, or a combination of each:

- boreholes
- basins or lagoons
- ditches
- controlled flooding.

Boreholes have been found to be most effective in hard or fractured rocks, with the other methods more applicable in softer strata. In the context of minerals operation and sensitive ecological sites, it is likely that lagoons and ditches will be the most practical applications. These are illustrated in Figure 13.

Factors Affecting Recharge

9.4.4 Three factors are of critical importance when considering an infiltration scheme:

- infiltration capacity, analogous to permeability but dependent on the head of the water present, affects how much water can be infiltrated
- suspended sediment loading which affects infiltration capacity
- chemical compatibility between the recharging water and receiving groundwater

9.5 Important Considerations When Recharging Water

9.5.1 In considering a recharge scheme at a particular location, the lagoons or trenches will generally be situated between the excavation and the nature conservation site. The following factors should be carefully considered:

The Need to Recharge the Water Table

9.5.2 The dependence of flora and fauna on high level groundwater needs to be justified. There is obviously no point in recharging the water table if communities are dependent on stored soil water, above the capillary zone, for example.

An Assessment of the Likely Volume of Water Required

9.5.3 Good site investigation data and previous experience of working in an area should enable this to be made as well as for designing the dimensions of the trenches or lagoons. The latter is obviously important in terms of land take and availability. In some cases, however, field trials could be required.

9.5.4 Trenches or lagoons do not necessarily have to extend to the saturated zone because with continued operation the ground will eventually become saturated and a groundwater mound will form. In fact, if they do this can hinder maintenance such as desilting, if long-term operation is required. Most applications, for recharge systems will be in relatively shallow mineral deposit, however, and are likely to intercept the water table. The side slopes should be stable, typically 1:1.5 or 1.2, with a layer of course, well-sorted material on the base 150-200mm in thickness. This has been shown to increase the infiltration capacities that are obtainable[27] and also helps when maintenance is required. A typical cross section is shown in Figure 12.

Water Quality

9.5.5 Use of dewatering water will remove the potential problem of chemical compatibility, outlined above, in the vast majority of cases. In many operations, however, this water is used to wash the mineral and becomes laden with a high degree of silt and sometimes with other contaminants. If it is to be used for infiltrating, consideration should be given to whether it is utilised before or after process washing.

Operational Control

9.5.6 Artificial recharge schemes have the potential to infiltrate large amounts of water and it should be remembered that increasing groundwater levels over the natural variation for extended periods could be just as detrimental as prolonged lowering. Careful monitoring as part of the operation of the scheme is therefore of fundamental importance and specific monitoring installations should be integrated into the system for this purpose.

Silt

9.5.7 Silt within the infiltrating water is not necessarily a hazard as long as the lagoons or trenches are not allowed to overtop. It should be regarded more as a hindrance in that it can eventually reduce the infiltration rate and is therefore undesirable. Settling of solids in lagoons may therefore be favoured prior to infiltration, rather than maintenance. Pumps can also be floated so as to avoid drawing in settled material from the base of settling lagoons.

9.5.8 In some cases, however, especially where very colloidal clays are associated with mineral, it could be more practical and/or economic to provide a separate source of infiltration water, such as a borehole (see case study overleaf).

CASE STUDY: POVINGTON AND GRANGE HEATHS SSSI, DORSET

Concern was expressed that the proposed extension to an opencast ball clay extraction at Squirrel Cottage could damage an adjacent valley mire with associated assemblages of wet, humid and dry heath. A detailed geological study of the SSSI and the extraction area revealed the presence of a natural zone of silt and clay lenses within the generally sandy overburden between the two areas.

Monitoring of groundwater level data proved that the mire was supplied by confined groundwater but that it reacted very differently to that which was encountered on the excavation side of the silt and clay lenses. The hydrological interpretation was that the lower permeability zone within the overburden would act as a natural barrier to dewatering of the mire, however this was insufficient justification for the Planning Authorities.

During the delay in planning the variations in groundwater levels and chemistry either side of the 'barrier' were regularly monitored and a mitigation scheme involving infiltrating groundwater was proposed. Owing to the confined space and access difficulties between the working area and the mire, lagoons rather than trenches were preferred. It was also decided, because of logistical difficulties within the working area and the extremely fine sediment problems caused when seepage water came into contact with the ball clay deposit, that a borehole would be a more practical and cost-effective source of infiltrating water.

The borehole was located outside the area of excavation to intercept groundwater on the operational side of the silt and clay lenses and fed water to the lagoons by a simple system of valves and hoses. The configuration is shown in Figure 12. A two month trial with monitoring was designed involving pumping only, infiltrating only and a combination of both. The objective was to 'overstress' the groundwater regime by pumping (this could be interpreted because of the excellent background data which had been obtained during the planning delay), to see if leakage from the mine occurred, and if it did, to assess the effectiveness of the recharge lagoons in building a hydraulic barrier to the mineral working as shown in Figure 13.

The outcome of the test was to prove that the original hydrological interpretation had been correct and that the natural barrier would indeed prevent dewatering by the proposed extension. It also showed, however, that the lagoons were an effective means of maintaining levels.

Permission for the extension was granted. Built into the consent was a condition for regular monitoring of specified boreholes and of feedback of the data on a quarterly basis to the Local Authority. The test lagoons and borehole remained in place as an emergency form of mitigation, to be operated at short notice if necessary. They have never been required.

CASE STUDY: WOLLASTON MEADOWS SSSI, NORTHAMPTONSHIRE

Covers an area of 11.48 Ha in the alluvial floodplain of the River Nene in Northamptonshire and is the largest known example of Meadow Foxtail - Great Burnet neutral grassland in Great Britain. It was designated in 1985. Its location is shown in Figure 13.

It is bounded on its western margin by a disused railway and on its south eastern margin by the Wollaston Brook, a tributary of the Nene, which flows through the northern part of the site.

Dry working of alluvial gravels in the vicinity was considered as a significant risk to the SSSI because of the drawdown in water table.

Initially, extraction was to the south of the SSSI. Dewatering was prevented by a short section of recharge trench into the gravel aquifer, in conjunction with an overburden/clay barrier as shown in Figure 14. Monitoring boreholes were included between the trench and the SSSI and levels were monitored regularly throughout the operation which proved successful in maintaining levels.

The working experience together with 2 years monitoring data gave confidence that a similar scheme could be successful working two extensions to the north and south east of the site as shown.

9.6 Infiltration Schemes as Methods of Permanent Mitigation

9.6.1. In the majority of cases, infiltration schemes will be a temporary measure, only required during the working of mineral, because the effect of dewatering is itself temporary. In most instances, groundwater levels can be expected to recover to be at, or near, those originally encountered, although this is not always the case (Section 5.4.11).

9.6.2 In some circumstances, however, simple infiltration schemes can be practical methods of mitigating permanent effects caused by the restoration proposals. As such they also provide the opportunity for some environmental enhancement. Two examples of permanent schemes are considered below:

- loss of recharge caused by less permeable infilling was described in Section 5.4.6 and is illustrated by the following case study from Dorset

- loss of temporary storage caused by excavation (Section 5.4.5) is illustrated by the concept of the compensation pond.

CASE STUDY: PROPOSED CONTAINMENT LANDFILL, ADJACENT TO HEATHLAND SSSI, DORSET.

Sand is currently extracted from a ridge which forms a divide between two surface water catchments. Clay layers are present within the sand on the southern part of the excavation. The SSSI borders the workings to the south and includes dry, humid and wet heathland with discrete flush communities.

Site investigation showed the water table to be below the base of the excavation, however perched water was shown to be present above the clay layers in the south of the site which supported the presence of small pockets of wet heath and flushes close to the excavation boundary (Figure 14).

The formation of a low permeability cap was of concern because the proportion of drainage would certainly increase in an area which naturally produces little runoff, and also because a large proportion of recharge to the wet flushes would be intercepted.

The drainage system was therefore designed so that it collected surface flows generated by the capping and infiltrated these into the undisturbed strata away from the landfilled area. The simple design consisted of a peripheral ditch with a number of lagoons on the southern margin which were originally designed as silt lagoons for use during the operational phase. Being slightly deeper than the ditch, the lagoons would remain wetter for a longer period and, in time, would add diversity to the local ecology.

Compensation Ponds and Mitigation Against the Loss of Temporary Storage

9.6.3 Many mineral workings, particularly hard rock quarries but also sand and gravel operations, terminate at the water table. Compensation ponds are designed to mitigate the loss of temporary storage which is caused by the removal of mineral from above the saturated zone (see Section 5.4.5) and are positioned in the zone of natural water table fluctuation. The rims coincide with the maximum winter water table level with the beds at, or below, the minimum summer water table level, (Figure 15). The ponds therefore fill during the winter and gradually drain during summer months.

9.6.4 The ponds are designed so that they hold a particular volume of water, corresponding to that which was previously held in temporary storage by the unsaturated zone prior to the removal of mineral. The volume is therefore calculated by reference to the specific yield of the particular aquifer, which is defined as the proportion of water which would drain from a unit volume of aquifer under gravity.

Typical specific yields (for the unsaturated zone) are:

Sand and Gravel	10 - 20%
Chalk	2 - 5%
Greensand	2 - 10%
Oolite Limestone	1 - 5%
Carboniferous Limstone	0.5% - 2%

9.6.5 The behaviour of these ponds is well understood, having been created fortuitously in now abandoned rock quarries in the Mendips such as Emborough and Waterlip and in gravel workings in Wiltshire and Dorset. The compensation pond begins to operate at the end of the winter recharge period, by supporting groundwater levels in the zone of water table variation to the same extent as the unsaturated zone did before it was removed. As winter recharge resumes, the pond plays the same part as the unsaturated zone by absorbing heavy rainfall and attenuating the reaction of springs and streams.

9.6.6 The water is a compensation pond is open to daylight and so tends, in time, to develop some of the characteristics of surface water, supporting plant and animal populations. Its quality is therefore inferior to that of the groundwater which it replaces. To minimise this disadvantage, the NRA prefer that the surface area of the pond is kept small in relation to the total groundwater catchment area.

9.6.7 A compensation pond can be installed early in the life of a mineral working (possibly in an abandoned sump) and will continue to function inexpensively, with no pumping costs or other active management, so long as it is required, which is usually in perpetuity. Special legal agreements may therefore be required to ensure that the pond is not damaged, abstracted from or filled in after the cessation of extraction operations.

9.6.8 In order to specify the dimensions of a compensation pond, a hydrogeological site investigation must previously be carried out, with monitoring of the natural groundwater levels covering a period at least one year. The depth, shape and size of the compensation pond can then be specified.

(Courtesy: NRA, South Western)

9.7 Mitigation of Rising Groundwater Levels

9.7.1 With the exception of poor operational control whilst infiltrating, to which reference has already been made, rising groundwater levels, if they occur at all, are only likely to occur some time after extraction has finished. Two factors need to be addressed:

- establishing whether groundwater levels are rising

- establishing the significance of the rise

9.7.2 Confirming whether levels are rising above 'natural' levels requires monitoring data, prior to extraction commencing. This is not always easy to interpret, particularly if the extraction industry has been concentrated in a particular area for any length of time and is withdrawing, or if the new application follows an extended dry spell of weather. Notwithstanding these potential problems, monitoring of groundwater levels over a hydrological cycle prior to extraction (a minimum of 1 year) and during the operational life of a site, will be sufficient in most cases.

9.7.3 Establishing whether the rises are significant or not in nature conservation terms, is another matter (Section 3.3) and the general comments made above with reference to maintaining levels by infiltration also apply here. The significance, or not, of a particular rise will depend on the specific ecological and hydrological conditions which are present and will probably require inputs from experts of both disciplines.

9.7.4 In contrast to falls in groundwater level, which could be rapid in some circumstances, rises would probably take time, enabling mitigation to be carefully planned and executed. The most practical method of controlling groundwater levels is by drains, which would route excess groundwater to the surface water system. Drains could be buried, such as land drains commonly used by farmers, around the periphery of the site, or open features as ditches or channels. Unworked reserve, (ie gravel strips) could also be used.

9.8 Creation of Linear Open-Water Features

9.8.1 The creation of linear water features, within abandoned workings, requires special consideration because of the 'flattening' effect they have on the water table when formed perpendicular to the groundwater (Section 5.4.10). This could have implications to the ecology on the margins of the lake and is often undesirable in land drainage terms, in which case the National Rivers Authority would comment.

9.8.2 Mitigation is relatively straightforward, however, in that division of the ribbon feature into discrete pockets markedly reduces the effect, separate lakes with slightly different water levels being formed (Figure 7). The disadvantages might include some loss of reserve or 'additional' restoration works if material underlying the mineral is used for the intervening bunds. This may be offset, however, by the increased interest which can be created within the working, in addition to the hydrological benefits.

CASE STUDY: PIXEY AND YARNTON MEADS SSSI, OXFORD

Yarnton and Pixey Meads are ancient hay meadows in the flood plain of the River Thames near Oxford. The site is internationally important for its rich fauna which has adapted to shallow groundwater conditions and for its long management history.

The application for the extraction of sand and gravel at Warton Rectory Farm, a 122 Ha Site to the north of Yarnton and Pixey Meads, was submitted in 1983 and gave considerable concern because of the sensitivity of the site to groundwater conditions.

Prior to extraction commencing a hydrogeological investigation was undertaken of the SSSI and extraction area to define the characteristics of the gravel aquifer which included pumping tests and over two years of water level monitoring data. The results were utilised to produce a computer model of the area which was then used to assess what kind of drawdown effects below natural variations would be likely beneath the Meads.[23]

Following the results of the computer modelling the original phasing pattern of the workings was altered. This allowed extraction to commence at a reasonably safe distance from the Meads, whilst a 60m clay bund was engineered on the southern boundary of the site. However, placing the perimeter seal necessitated some dewatering of the aquifer adjacent to the SSSI which monitoring indicated was slow to recover.

A recharge trench was therefore constructed on the SSSI side of the bund which very quickly caused the water table to recover.

One of the aspects of the site is that the River Thames feeds the aquifer beneath the Meads continued monitoring indicated that the peripheral seal was so efficient in preventing groundwater movement that groundwater levels started to rise on its southern (SSSI) side. The rechange trench was therefore tied into the Kingsbridge Brook to act as a groundwater relief channel.

9.9 Mitigation of Surface Water Effects

NRA Consents

9.9.1 With the exception of dewatering works, all abstractions and discharges from mineral workings and restored or abandoned excavations are subject to National Rivers Authority permissions. These include:

- Abstraction Licences: which covers the quantity of water which is taken from either surface or groundwater for any use.

- Discharge Consents: which control the quality and quantity of water which may be discharged from the site and usually have an industrial application.

- Land Drainage Consent: which controls drainage from the site, both during and after working in terms of route and quantity.

9.9.2 The permissions are designed to control water within a site and ensure that the integrity of the surface water system outside the site is maintained. In general, specific engineering proposals to established methodologies, such as those used by the coal industry[28], are required for the permissions to be obtained. These include:

- sizing of interceptor ditches and peripheral drains
- design of silt lagoons
- design of outfall structures and channels
- design of flood attenuation ponds where a final landform has the potential to increase natural runoff

9.9.3 In most cases the issue of the necessary licences should provide sufficient mitigation for sensitive environmental areas, subject to good operational control, such as the maintenance of silt lagoons.

9.9.4 Particular attention is necessary where discharge into a nature conservation site is required, to ensure that it is controlled in a suitable manner. Consideration should be given both to the method of discharge (ie whether point or diffuse discharge is necessary and/or possible) and the sensitivity of the receiving ecology. In some cases this may require a high degree of silt control.

9.9.5 In addition to the use of lagoons, sediment may be controlled by a number of methods, such as oversized, vegetated channels, grassed swards, and reed beds[29].

Mitigation of Water Level Changes

9.9.6 The main method available for controlling water levels is by the use of outfall structures, which may be either temporary or permanent features. Two examples of their use are given below:

- the use of stop logs or a penstock to maintain water levels in a small watercourse if it becomes apparent, for example, that dewatering works are lowering levels. These are an ideal method of emergency works in that they are cheap and relatively easy to install.

- the use of an engineered outfall, such as a weir to control water levels in an abandoned working rising above a particular level.

The above could be subject to NRA consents.

Mitigation of Surface Flows

9.9.7 Mitigation of reduced surface flows, for example from regional groundwater effects (eg. Section 5.4.10) is extremely difficult and could require artificial stream support by measures such as lining or pumping from groundwater. In some cases these measures could be necessary in perpetuity.

CASE STUDY: JOES POND NATURE RESERVE, CO DURHAM

Joe's Pond Nature Reserve is located within abandoned clay pits of an old brickworks in County Durham and is owned and administered by Durham Wildlife Trust. There were concerns that the proposal opencast coal extraction in an adjacent area could seriously affect the water holding capacity of the pond and pollute the surface water supply.

Site investigation of the pond and the surrounding areas suggested that there was no preferential drainage patterns into the underlying coal measures either through previously worked seams or high permeability glacial deposits. Furthermore groundwater within Coal Measures was significantly below the water level in the pond. It was concluded that the pond was surface water fed and that advance dewatering would not affect its integrity, principally because of the low permeability of the clay.

It was recognised, however, that the excavation would affect the surface water catchment to one of the pond inlets. Mitigation concentrated on maintaining this with, clean runoff intercepted by the workings.

Planning permission was granted subject to monitoring requirements being built into a Section 106 Agreement. This included monitoring mineral levels and indicator species to measure quality changes within the pond and the provision of an action plan in case of a catastrophic event.

9.10 **Mitigation of Regional Effects**

9.10.1 Regional effects have the potential to significantly affect the local hydrological regime of areas of nature conservation. Some regional hydrological effects may not be regarded as a problem in terms of water resources yet may pose a potential threat to nature conservation. The change to the drainage pattern in the Cotswold Water Park is a case in point.

9.10.2 Mitigation of a particular area of nature conservation is possible on a local scale whilst mineral is being worked. On the basis that prevention is better than cure, it is much better that the overall impact of such regional effects is adequately dealt with during the formation of the Development Plan (Section 2.5.5) and EN will liaise with the planning authorities and NRA to ensure that nature conservation interests are taken into consideration at this stage.

9.11 **Summary**

9.11.1 The following tables summarise the main types of mitigation which are available to mineral operators. The table is for guidance and should not be viewed as a comprehensive checklist to be used in every case. The methods shown should only be adopted after careful consideration on a site specific basis by an experienced hydrologist/hydrogeologist.

Table 9.1 - Summary of Available Mitigation Measures

EFFECT	MITIGATION METHOD		TECHNICAL ANNEXE REFERENCE
	1. Planning Stage		
Groundwater & Surface water effects	Choice of Site	Choose to work site outside the zone of influence of nature conservation interest	9.2.3
Groundwater Drawdown	Stand off	Leave an unworked margin to reduce drawdown effects	9.2.4
"	Depth	Limit the excavation depth	9.2.5
Groundwater & Surface water effects	Phasing	Consider alternative phasing of works	9.2.6
"	Direction of Working	Work towards a site of nature conservation interest	9.2.6
	2. Operational Stage - Methods of Working		
Groundwater & Surface water effects	Size of Working Area	Minimise the plan area of active working	9.3.2
"	Wet or Dry Working	Consider working wet as alternative	9.3.3
"	Cellular Working	Work and restore in smaller units to minimise areal effects	9.3.2
	3. Operational Stage - Controlling Groundwater Levels		
Groundwater drawdown	Boreholes	Recharge through boreholes	9.4.3
"	Recharge Basins or Lagoons	Recharge from Ponded Water	9.4.3
"	Recharge Ditches	Recharge from Ponded Water	9.4.3
"	Controlled Flooding	Release of water over washland	9.4.3
"	Cut Off	Use vertical clay seals or cut off walls to minimise groundwater drawdown	9.4.3

Tabel 9.1 : Summary of Available Mitigation Measures (continued)

EFFECT	MITIGATION MEASURES		TECHNICAL ANNEXE REFERENCE
	3. Operation Stage - Controlling Groundwater Levels (continued)		
"	Partial Exclusion	Use a semi permeable membrane or geotextile to inhibit groundwater movement into the site	9.3.6
	Relief Wells	Release of groundwater to the surface	9.7.4
Rising Groundwater levels	Relief Channels	Lower high groundwater by surface drains	9.7.4
"	Linear Water Features	Divide large ponds into smaller units	9.7.4
"			
	4. Operational, Restoration and Aftercare Stages - Surface Water Management		
Reduced overland flow	Bypass site	Careful design of interceptor and peripheral drains	9.9.2
Downstream water quality	Water Quality Control	Design of silt lagoons, vegetated channels or reed beds	9.9.5
Increased flood risk downstream	Flood attenuation	Design of ponds or linear ditch features	9.9.2
Reduced flows downstream	Augmentation	Discharge of dewatering water at discrete points on affected stream	9.9.7
"	Augmentation	Artificial stream support from other sources	9.9.7
Water levels in nature conservation area	Control Surface Water Levels	Use weirs at discrete outfalls	9.9.6
	5. Operational, Restoration and Aftercare Stages - Compensation Storage		
Loss of aquifer storage	Compensation ponds	Compensate for loss of aquifer storage	9.6.3

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Aggregate:	Materials used for mixing with a matrix to form concrete, macadam, mortar, or plaster; or used alone as in railway ballast or graded fill.
Alluvium:	Sediment deposied by a river, commonly composed of sand and gravel, although alluvium may also be formed of clay or silt
Aquifer:	A water bearing bed of strata. Usually an aquifer is able to transmit economically significant quantities of water by virtue of its porosity as permeability
Artificial Recharge:	Induced replenishment of groundwater (see recharge)
Ball Clay:	A type of high quality clay formed by the natural reworking of china clay
Baseflow:	The component of streamflow which originates as groundwater
Batter:	The sideslope of a mineral excavation
Bund:	A wall, often constructed of earth, used to screen the mineral working
Compensation Pond:	A lake formed within the zone of water table fluctuation which mitigates the loss of storage in the unsaturated zone caused by the mineral excavation.
Confined:	The term given to an aquifer which is fully saturated, where the groundwater is pressurised by lower permeability strata above and below to greater than atmospheric pressure. Confined aquifers do not have a water table but exhibit a piezometric surface.
Derogation:	Unnatural effect on water sources, such as streams or wells, which is often noticed as a loss in flow or yield.
Dewatering:	The pumping of water either to reduce the flow of groundwater into the excavation, or to diminish its pressure. Dewatering is most often used to allow dry working of the mineral.
Draglines:	Large cranes fixed with buckets used for excavating sand and gravel from beneath lakes by dragging the bucket through the mineral.
Drawdown:	Lowering of the water table or piezometric surface, most often caused by dewatering adjacent to mineral workings.
Dry Working:	Working of dry mineral, ie., from above the water table. Often used in conjunction with dewatering so that mineral normally below the water table can be excavated.

Evapotranspiration:	The net loss of water from the soil to the atmosphere due to the combination of plant uptake (Transpiration) and Evaporation.
Extraction:	The removal of mineral.
Freeboard:	The height difference between the water level of a lake and the lowest point of the surrounding land, usually on a weir or dam.
Geomorphology:	The description and interpretation of land forms.
Geotextile:	An artificial textile-like material used in civil engineering. Often formed of plastic.
Glacial Drift:	Characteristic sedimentary deposits left behind by a retreating glacier or ice-sheet.
Groundwater Configuration:	The shape of the phreatic (water table) or piezometric surface
Groundwater Gradient:	The slope of the groundwater configuration at a particular point (analogous to hydraulic gradient)
Hydraulic Gradient:	The slope on the surface of a body of water which causes it to move.
Hydrogeology;	The study of the geological factors relating to the earth's water, including its occurrence, distribution and movement.
Hydrology:	The study of all waters in and upon the earth, including underground water, surface water and rainfall.
Infiltration:	The passage of water through the surface of the ground.
Jet Grouting:	The injection of liquid into the ground which reduces its permeability by setting in fractures and pores.
Karst:	Limestone landscape showing a pattern of weathering similar to that of the Karst region of Yugoslavia. This type of topography is not produced by surface run off but by percolating groundwater dissolving the rock.
Leachate:	Liquid produced by the bacterial degradation of waste materials.
Mineral:	A structurally homogenous solid of definite chemical composition, formed by the inorganic processes of nature.
Mitigation:	Specific measures taken to prevent adverse impacts of a scheme

Overburden:	Material underlying a mineral deposit which usually has little economic value.
Permeability:	A measure of the relative ease with which a medium can transmit a fluid. It is a property of the medium and not of the fluid.
Phreatic Surface:	Commonly known as the water table. It is defined as the surface within an unconfined aquifer where the groundwater is at atmospheric pressure, below which the aquifer is saturated.
Physiography:	Synonym of geomorphology.
Piezometric Surface:	Represents atmospheric pressure within a confined aquifer. By definition it occurs above the top of the aquifer and may have unsaturated ground beneath it.
Pump Testing:	A test made by pumping a borehole or well for a period of time and measuring the response of water levels in order to determine aquifer characteristics, such as permeability and storage.
Recharge:	The process of which groundwater is replenished by the infiltration of rainwater.
Recharge Mound:	A localised rise in the water table on piezometer surface resembling a small hill, caused by artificial recharge from a borehole or lagoon.
Saturated Zone:	The zone of groundwater where all the voids in the rock or soil are filled with water. In unconfined aquifers this corresponds to the zone below the water table.
Secondary Permeability:	Permeability caused after the formation of a soil or rock, for example the cracks and joints formed by the dissolution of limestone.
Silt Lagoon:	An excavation constructed to settle out silt from water before it is discharged to a watercourse.
Slurry Trench:	A trench which is constructed and filled with a low permeability slurry, often clay based, in order to reduce groundwater flow into, or out of, an area.
Specific Yield:	A measure of the amount of water which drains naturally by gravity from an unconfined aquifer, expressed as a fraction of the volume of aquifer.
Storage:	A general term used to describe the amount of water held in an aquifer. In unconfined aquifers the amount of water which may be obtained is more accurately defined in terms of specific yield.

Sump:	A pond located in the deepest part of an excavation where water is collected and pumped from
Suspended Solids:	The solid pollutants in a surface water. In the minerals extraction industry this is most often caused by silt.
Transpiration:	See evapotranspiration.
Unconfined:	The term given to an aquifer which is not fully saturated, ie., it has a water table.
Unsaturated:	The zone between the land surface and the water table where air is present in pores. Saturated bodies such as perched groundwater may exist in the unsaturated zone.
Water Resources:	A natural concentration of water from which extraction is, or may, take place.
Water Table:	see Phreatic Surface
Wet Working:	The excavation of mineral from below the water table, often using Draglines.

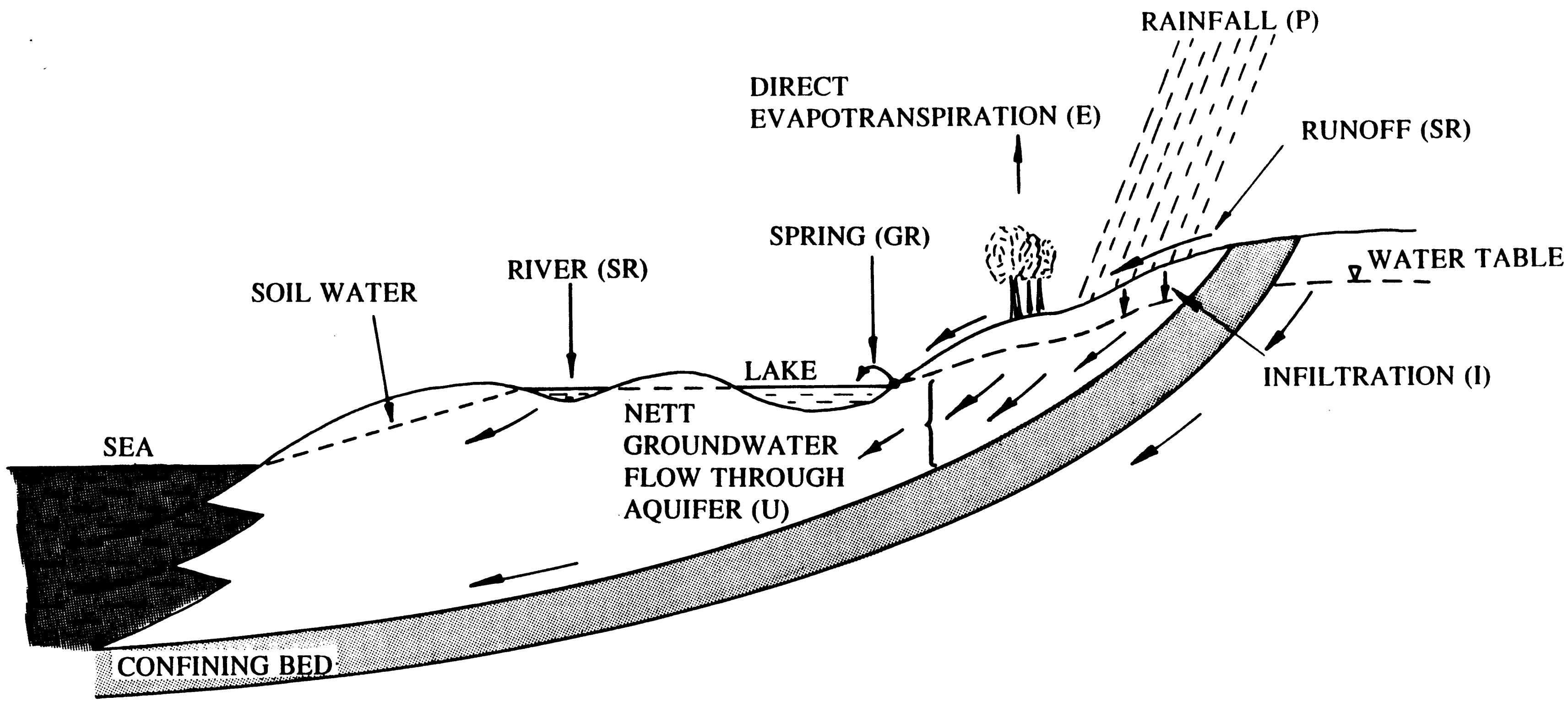


FIGURE 1:
DIAGRAMMATIC REPRESENTATION OF THE HYDROLOGICAL CYCLE (AFTER BRANDON, 1986[5]) FIGURES IN PARENTHESIS REFER TO THE WATER BALANCE IN SECTION 3.2.1.

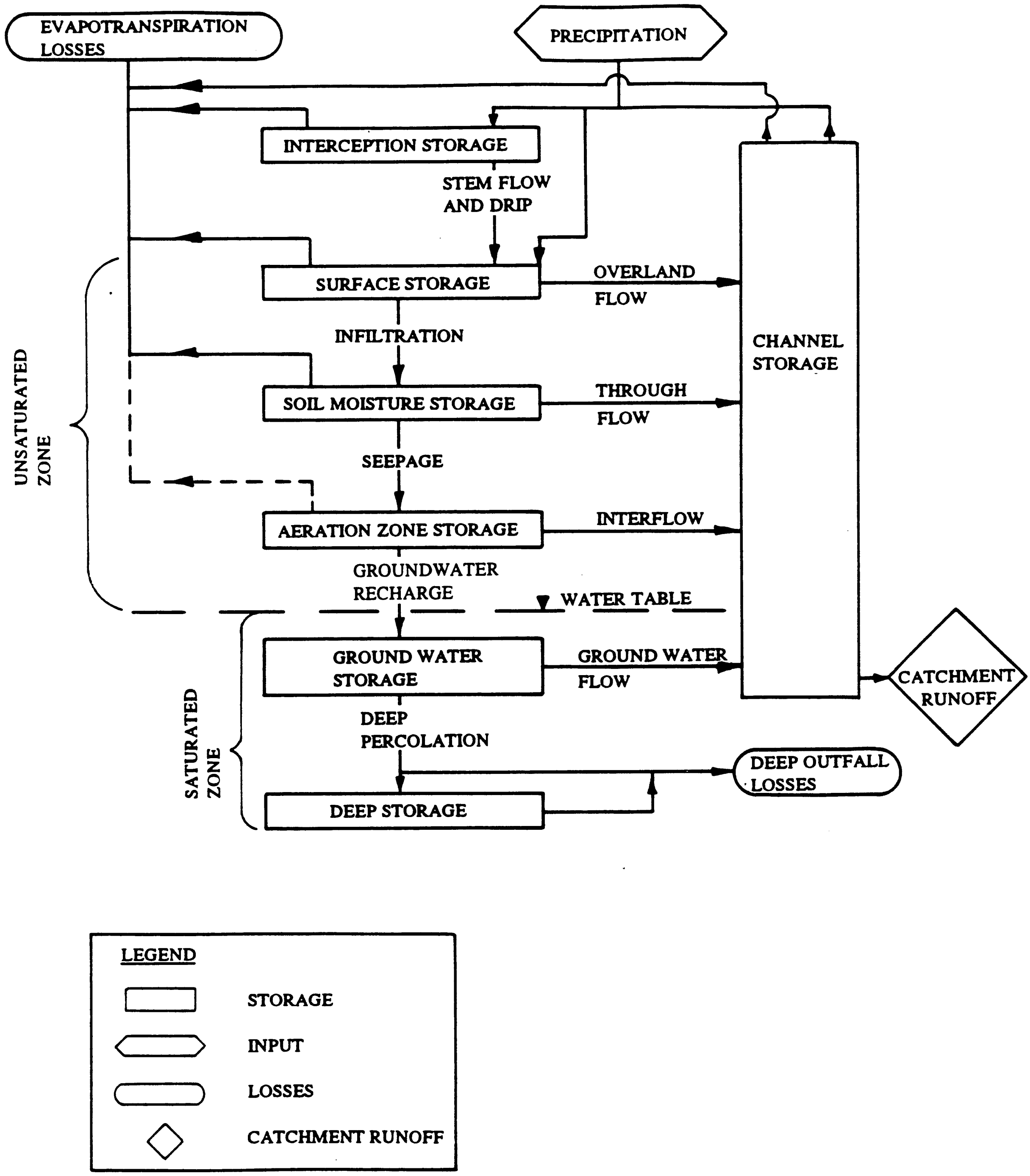


FIGURE 2:
SCHEMATIC REPRESENTATION OF THE HYDROLOGICAL CYCLE (AFTER CHORLEY 1969[6])

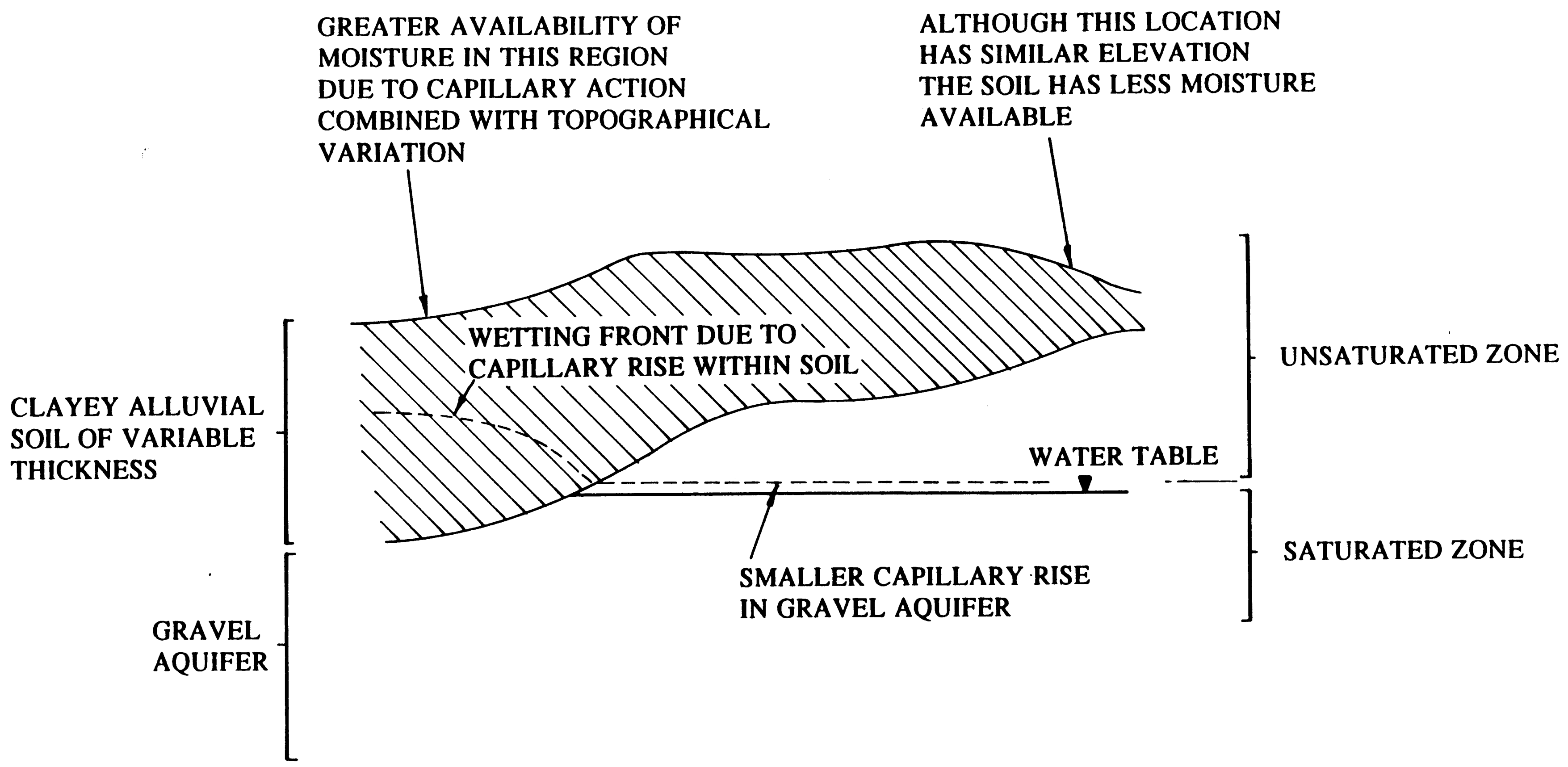


FIGURE 3:
SECTION THROUGH SOIL PROFILE SHOWING THE EFFECT OF
COMPOSITION ON SOIL MOISTURE THROUGH CAPILLARY RISE

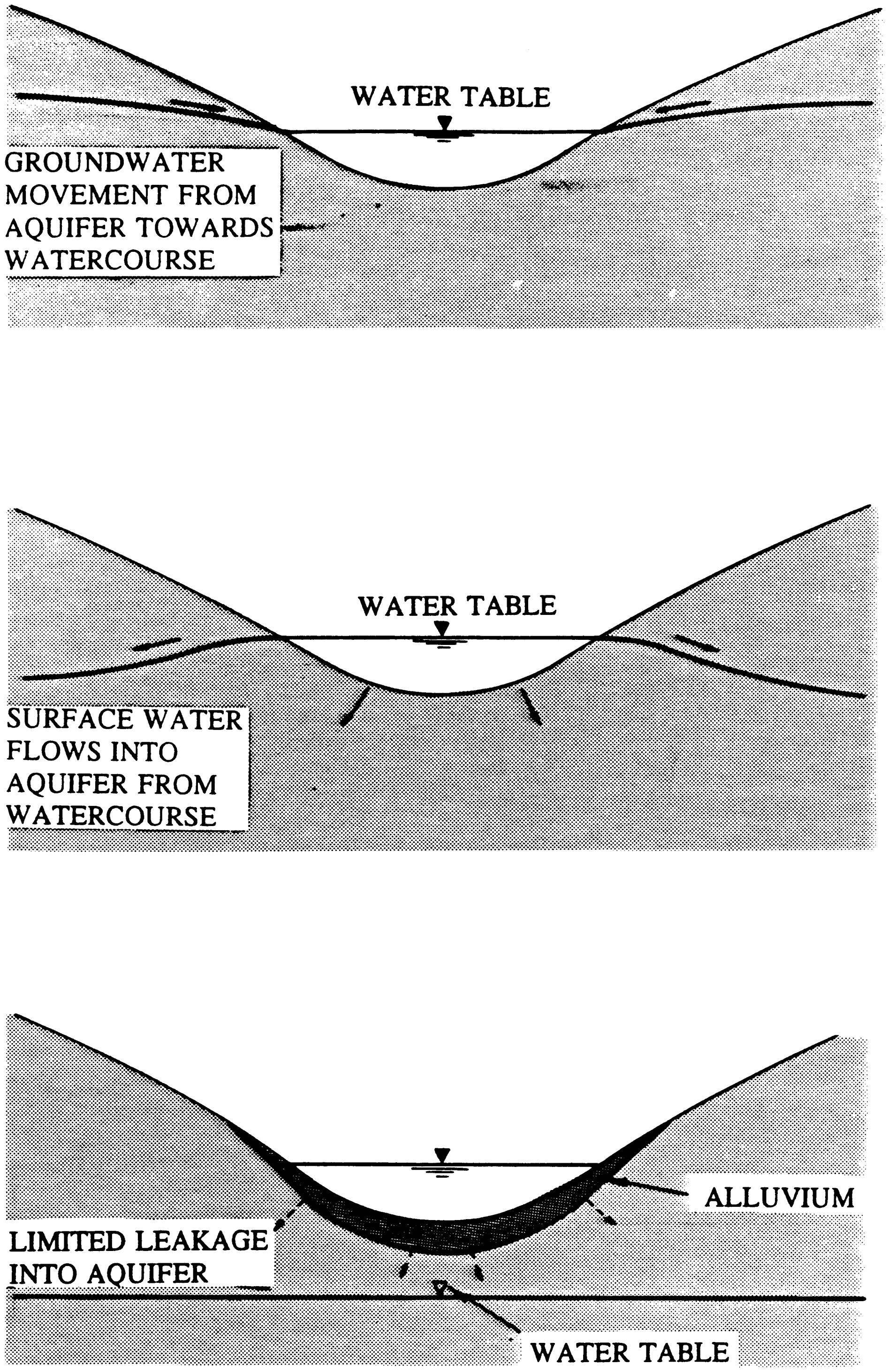


FIGURE 4:
SURFACE WATER AND GROUNDWATER INTERACTION SHOWING GAINING STREAM (TOP) LOSING STREAM (CENTRE) AND PERCHED WATER COURSE (BOTTOM)

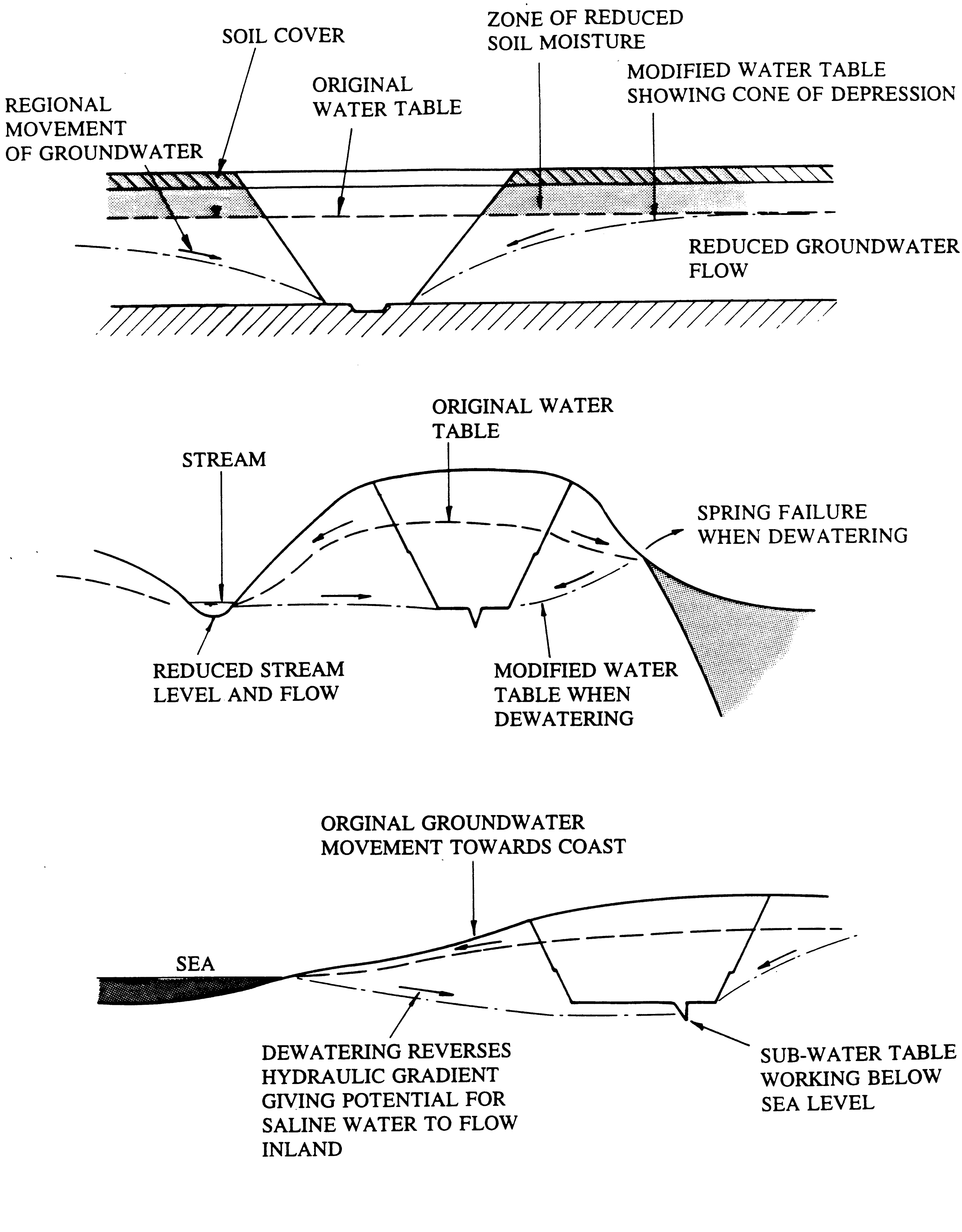


FIGURE 5:
EFFECTS OF DEWATERING ON GROUNDWATER MOVEMENT
SHOWING REDUCED SOIL MOISTURE (TOP),
SPRING FAILURE AND REDUCED STREAM FLOW (CENTRE)
AND SALINE INTRUSION (BOTTOM)

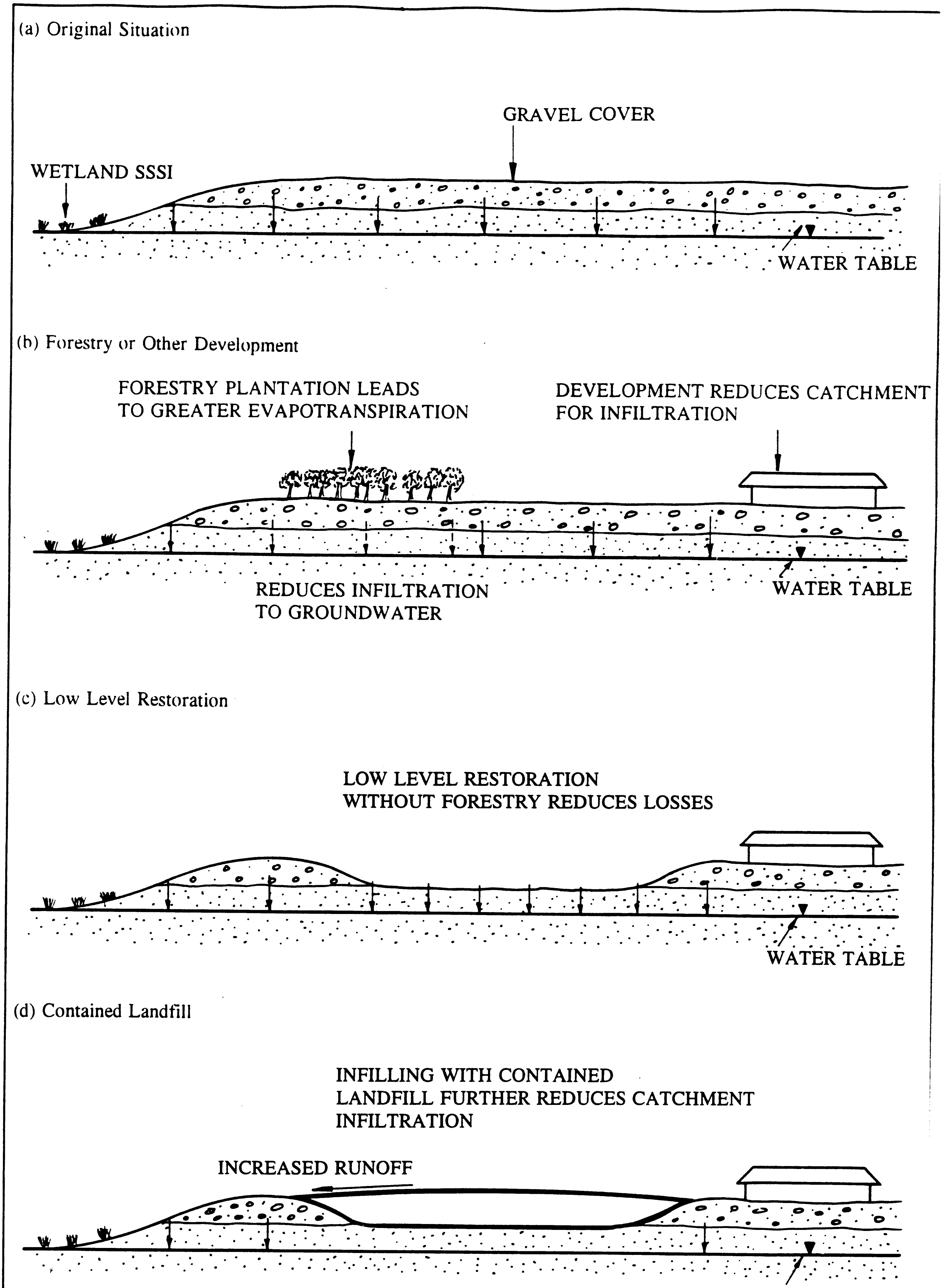


FIGURE 6:
THE EFFECTS OF ALTERNATIVE METHODS
OF RESTORATION ON INFILTRATION

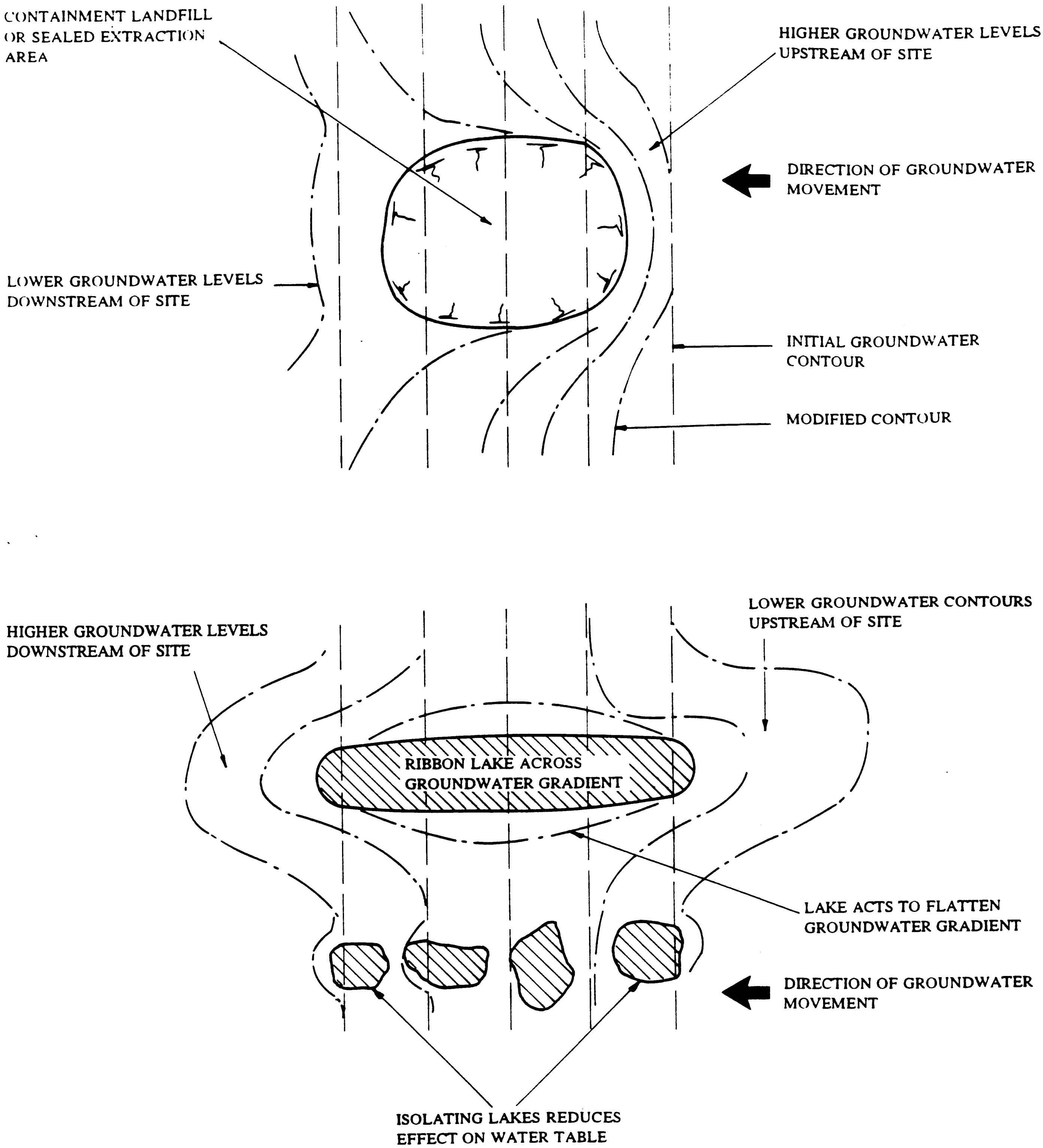


FIGURE 7:
EFFECTS ON GROUNDWATER GRADIENTS : CONTAINMENT LANDFILL OR SEALED MINERAL WORKING (TOP) AND RIBBON LAKE (BELOW)

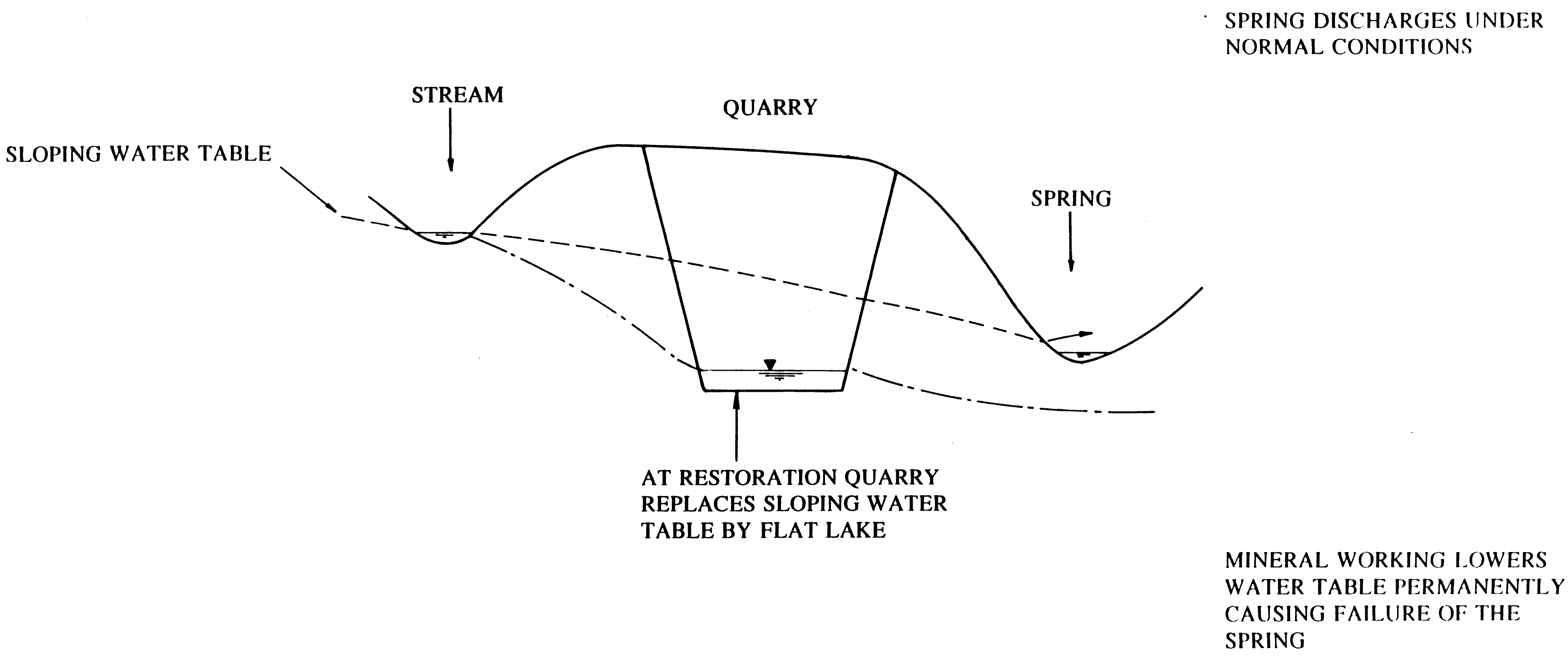
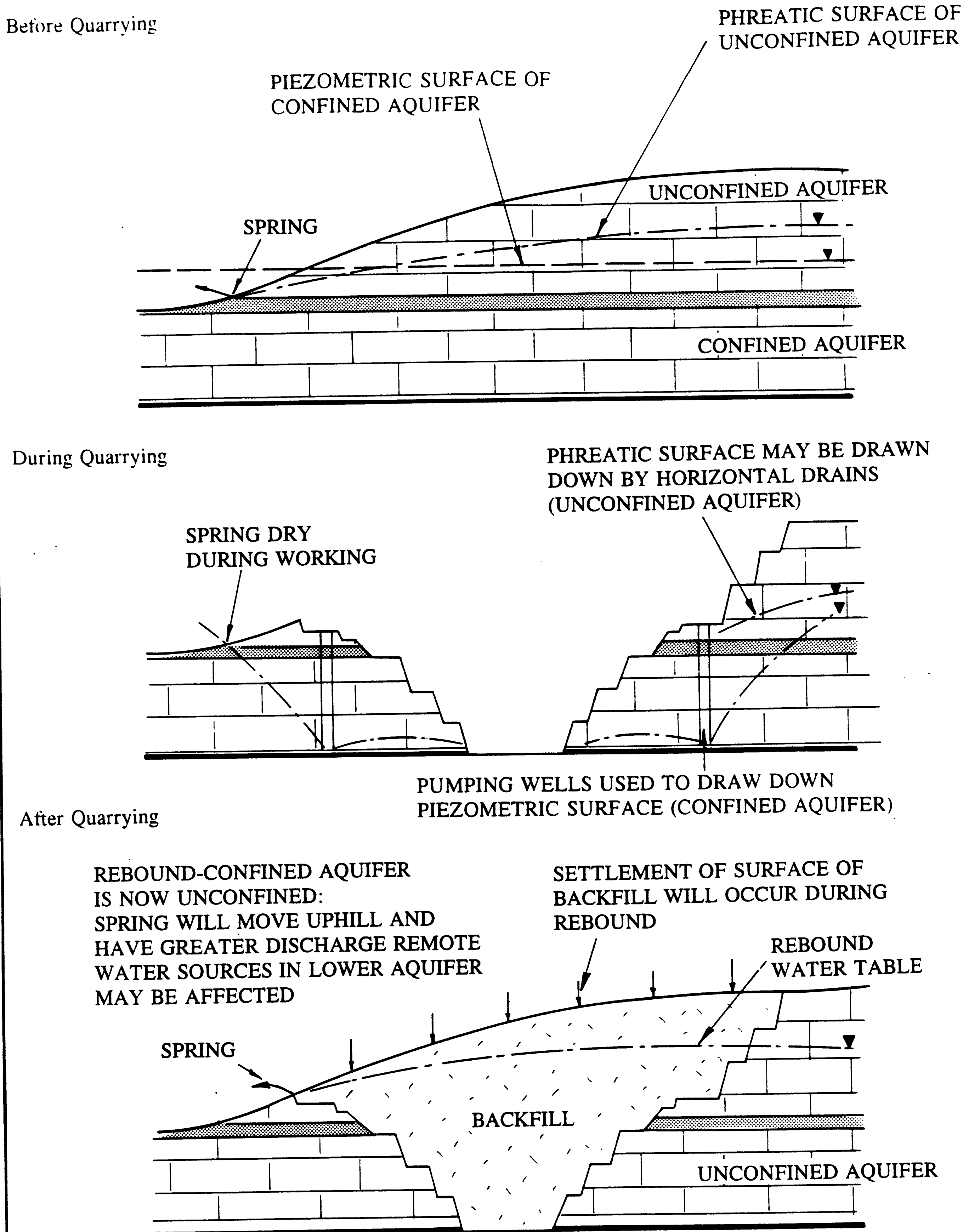


FIGURE 8:
SPRING FAILURE CAUSED BY MINERAL WORKING



REBOUND OF WATER AT THE END OF QUARRYING

FIGURE 9:
THE EFFECT OF WATER TABLE REBOUND ON MULTIPLE AQUIFERS WHICH HAVE BEEN JOINED BY MINERAL WORKING (AFTER DOE. 1988[11])

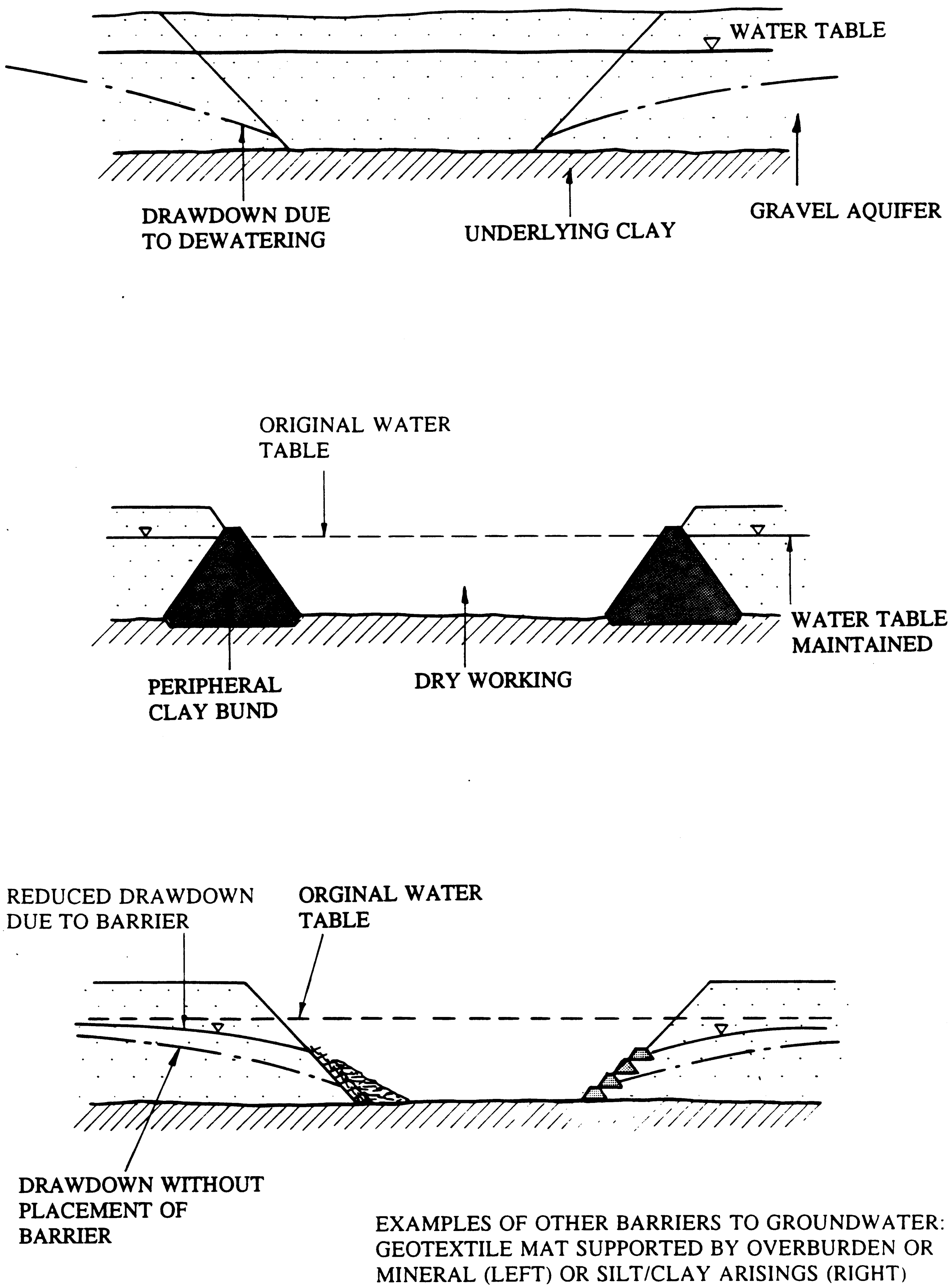


FIGURE 10:
EXAMPLES OF DESIGNS FOR REDUCING GROUNDWATER DRAWDOWN ADJACENT TO MINERAL WORKINGS:
TOTAL CUTOFF (CENTRE) AND PARTIAL EXCLUSION (BELOW)

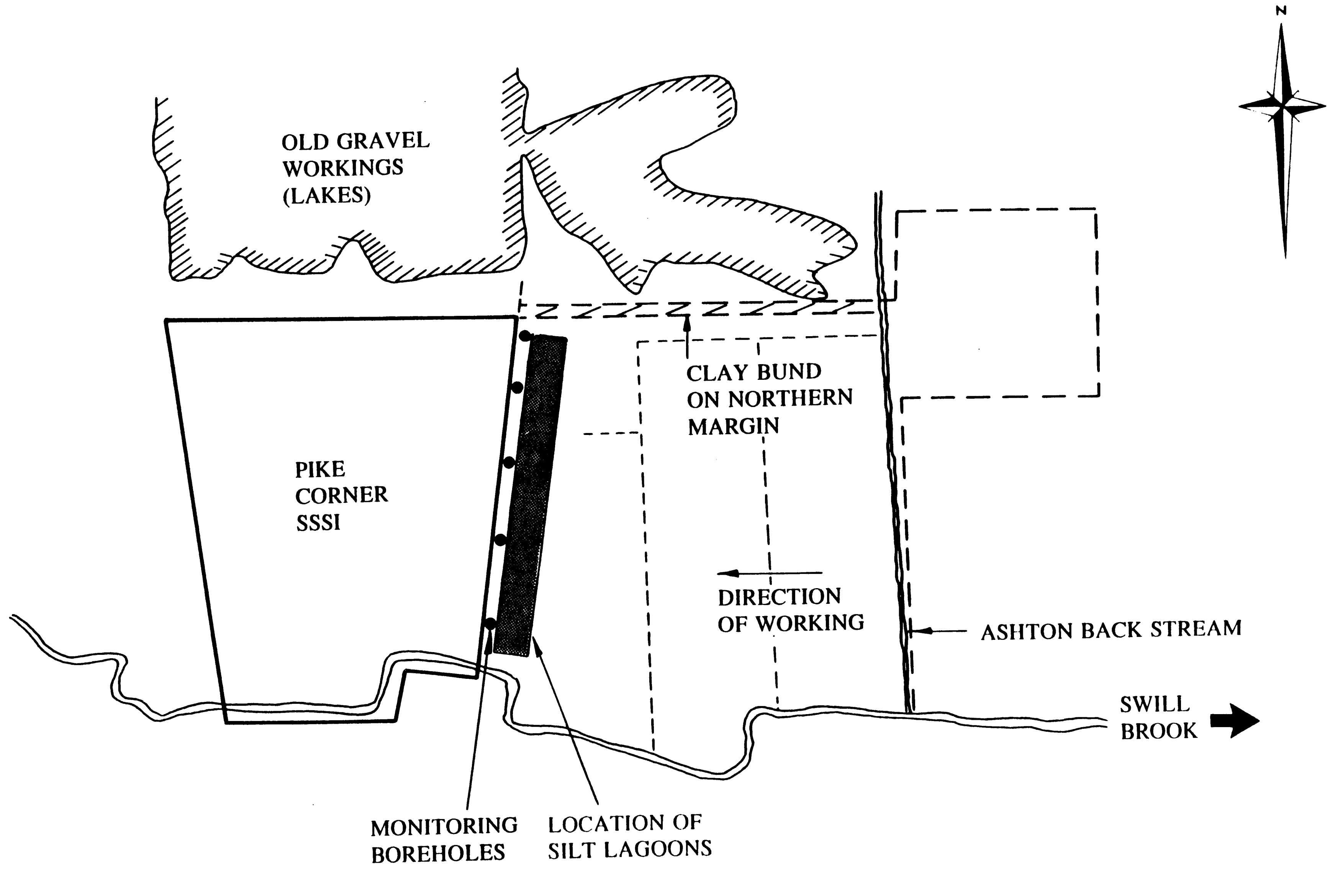


FIGURE 11:
SKETCH MAP OF PIKE CORNER SSSI AND THREE BRIDGES QUARRY, WILTSHIRE

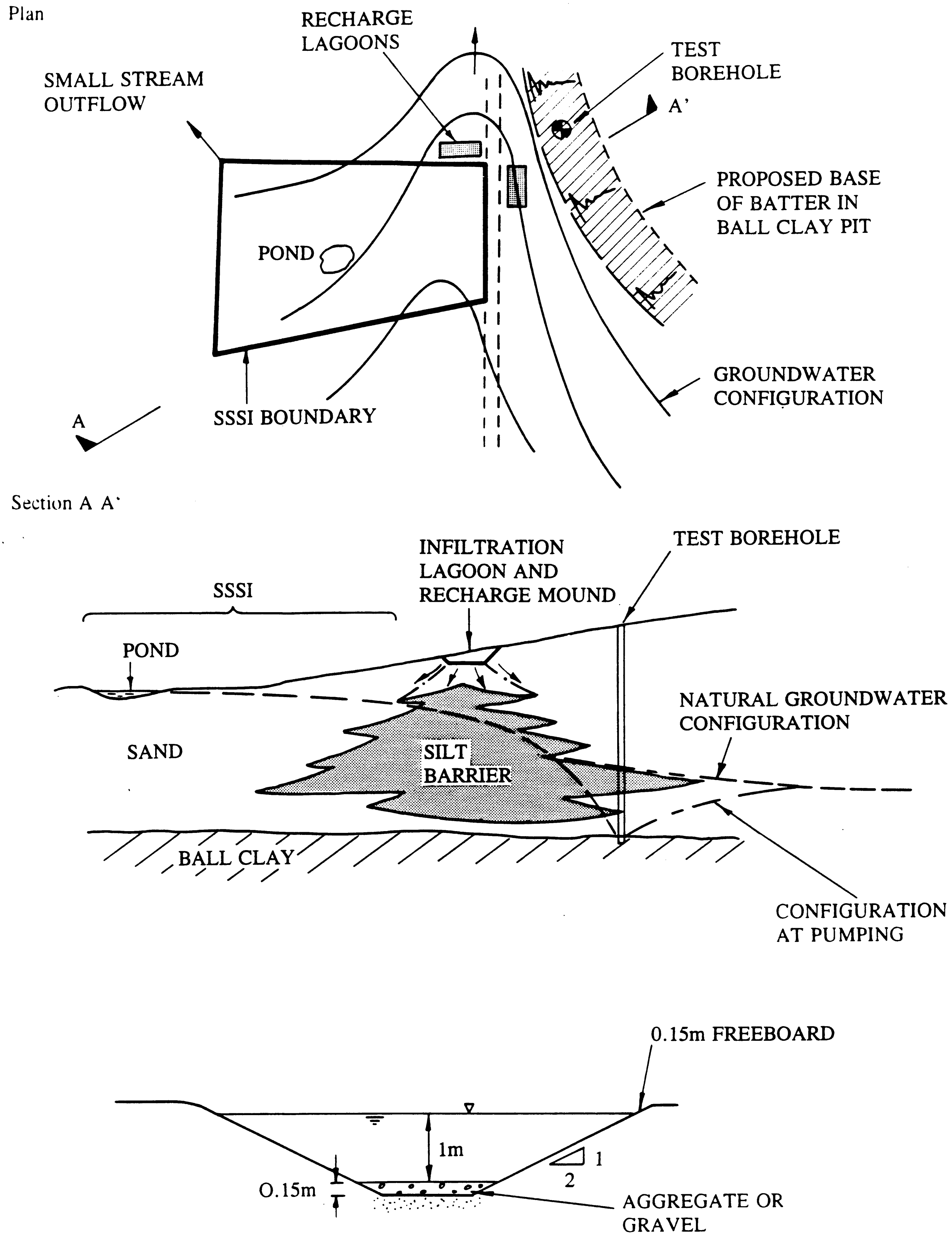


FIGURE 12:
SKETCH MAP OF POVINGTON AND GRANGE HEATH SSSI, DORSET SHOWING LOCATION AND GROUNDWATER CONFIGURATION (TOP) SUMMARY OF FIELD TRIAL (CENTRE) AND SECTION DETAIL OF RECHARGE LAGOON OR DITCH

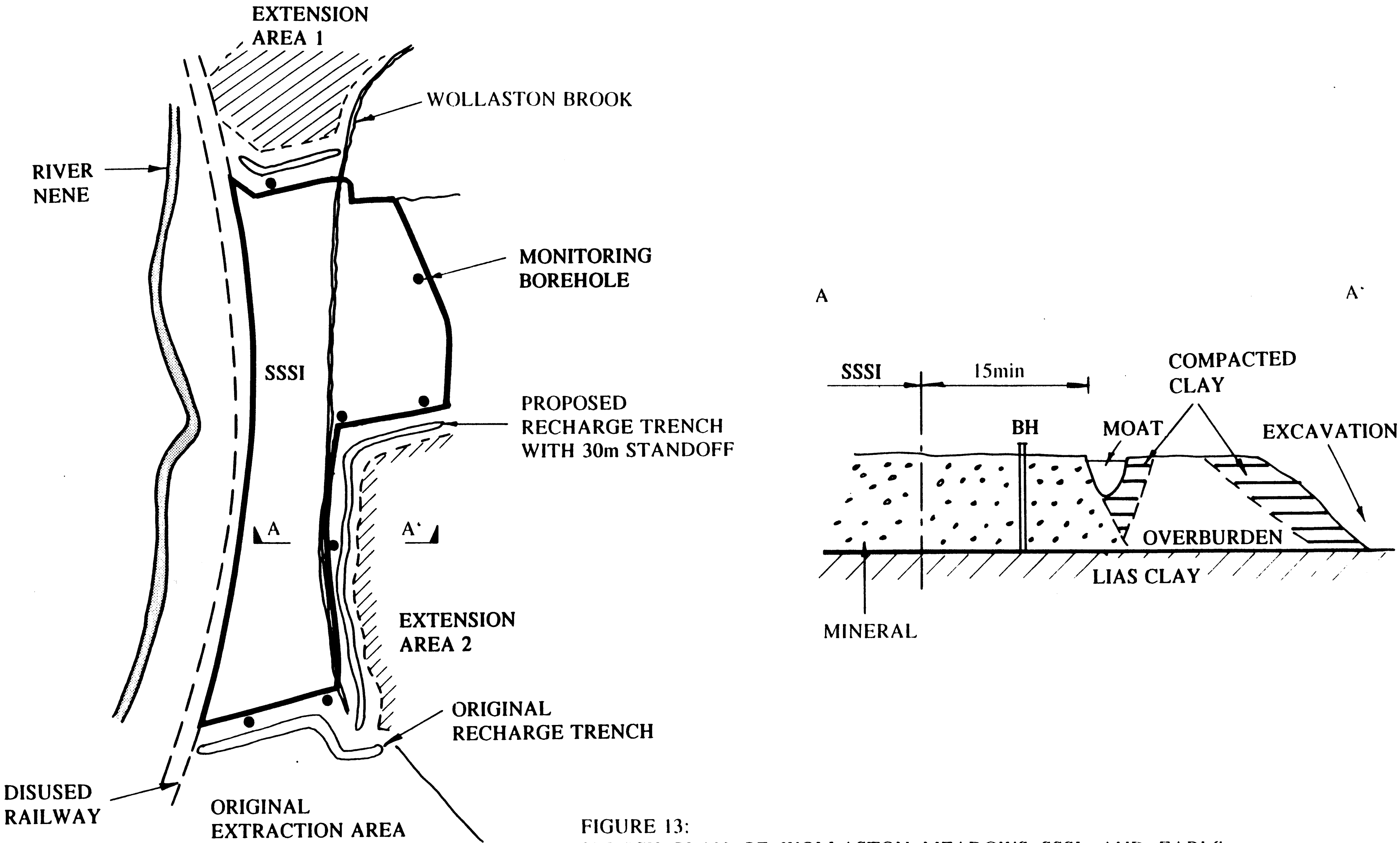


FIGURE 13:
SKETCH PLAN OF WOLLASTON MEADOWS SSSI, AND EARLS BARTON QUARRY NORTHAMPTONSHIRE SHOWING MITIGATION MEASURES AND DESIGN OF RECHARGE TRENCH

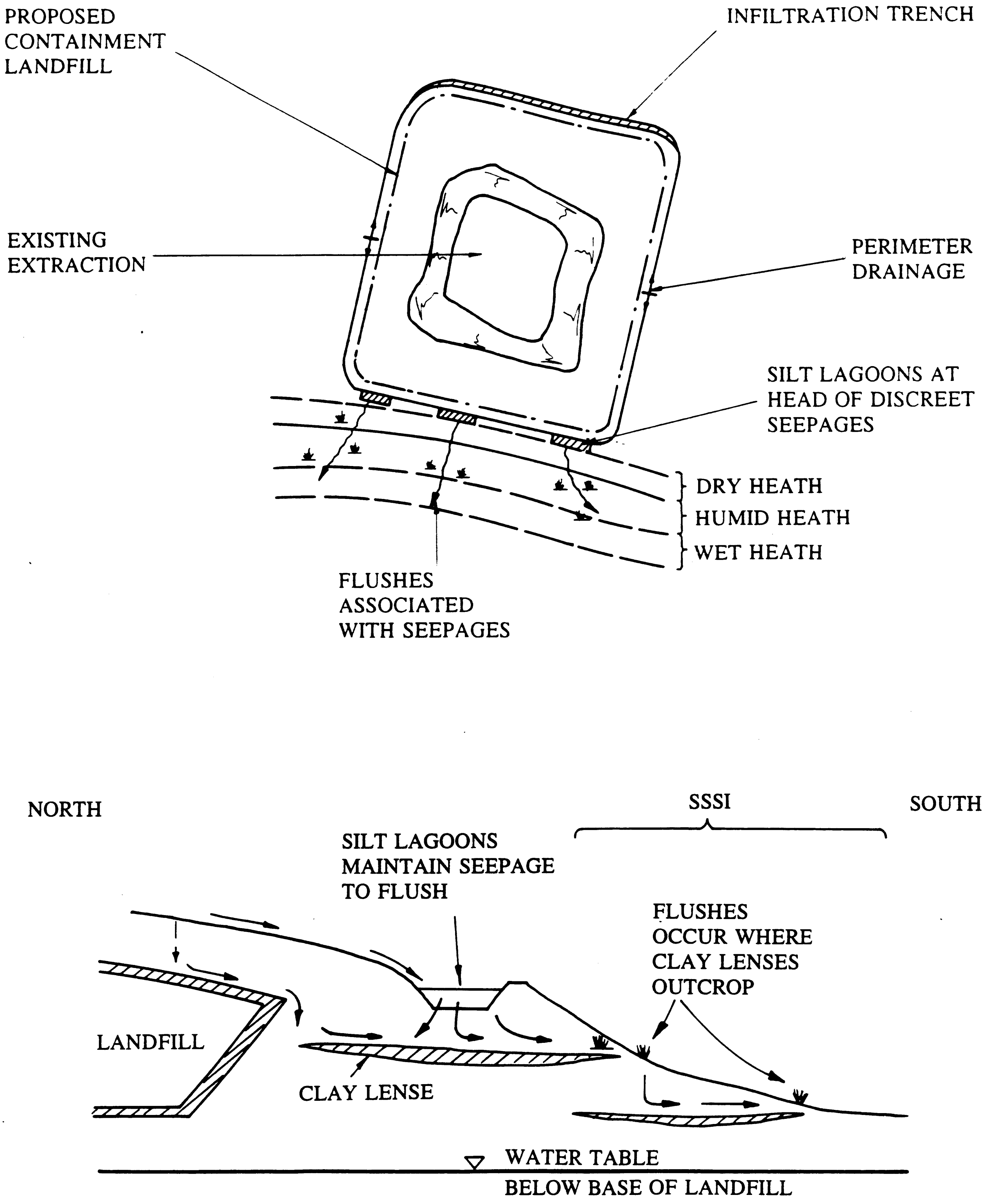


FIGURE 14:
RECHARGE AS A MEANS OF PERMANENT MITIGATION PROPOSED FOR CONTAINMENT LANDFILL ADJACENT TO HEATHLAND SSSI, SOUTHERN ENGLAND

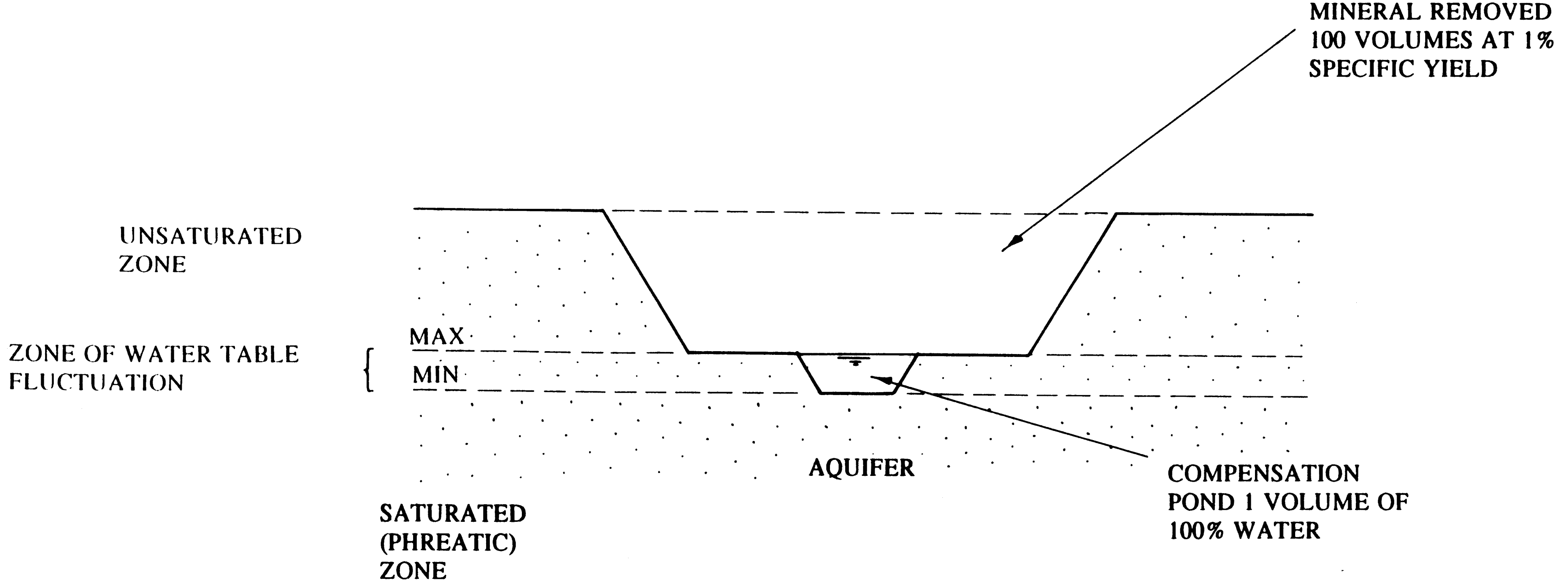


FIGURE 15:
HYDROGEOLOGICAL SECTION THROUGH COMPENSATION POND

Courtesy: NRA (South Western)

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