An assessment of the relative environmental sustainability of sub-water table quarries

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Statement of use
This report presents a review of the relative environmental impacts of sub-water table quarries, and in particular environmental issues to consider in assessing the relative sustainability of sub-water table mineral extraction.

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EXECUTIVE SUMMARY

Quarrying and mineral extraction in the UK is carried out in a wide range of geological and hydrogeological environments ranging from shallow excavations in unconsolidated deposits such as sands and gravels, to very deep quarries in ‘hard’ rocks such as Carboniferous Limestone or granite.

Whilst mineral extraction can usually, at least in part, be carried out in relatively dry conditions above the water table, often winnable mineral reserves extend beneath the water table and hence dewatering is required in order to maximise the winnable mineral and facilitate safe extraction at greater depths.

These operations have potential to impact upon the quality, levels and flow regime of groundwater and surface water resources. In general terms, the deeper and more extensive the quarry, the greater is the likely requirement for water management, and the greater is the potential for adverse impact on water resources. The main difference between sub and above water table quarries is in their restoration and after-use. Sub-water table quarries may be restored wet (e.g. to a lake for fishing or leisure) or dry/low level via diversion or pumping of groundwater in perpetuity.

Guidance and legislation regarding the quarrying industry and in particular in relation to groundwater has been reviewed. A review has also been undertaken of published information dealing with sub-water table quarries and a questionnaire was circulated within the Environment Agency with the aim of identifying the range of approaches to sub-water table quarrying in different hydrogeological environments. It was found that approximately 45% of the quarries identified have permission to extend beneath the water table and nearly two thirds of these are located in the Thames River Terrace deposits. Approximately one third of the sub-water table quarries are located on Major Aquifers (this reflects a large number of sand and gravel quarries in the Thames area where the Terrace Gravels are classified a Major Aquifer). Results of the questionnaire also indicate that the most common form of water management includes discharge of water to a near by watercourse.

The hydrogeological characteristics of the different environments dictate the appropriate method of dewatering. The hydrogeological characteristics are therefore detailed together with their relevance to sub-water table workings and the likely extent of environmental impact.

Potential environmental impacts as a result of sub-water table quarrying result due to:-

- the loss of groundwater storage - the consequence of this is limited in moderate and high permeability strata and likely to be very small in low permeability strata,

- dewatering - the consequence of this is limited in low permeability strata but can be significant in moderate to high permeability strata where the volume of water affected is high and water resources are most valuable. The impacts may include loss of groundwater resource; derogation of abstractions and groundwater fed watercourses; contamination of watercourses and damage to associated flora and fauna; reduction in water levels in wetland areas; modification of groundwater flow regime; groundwater contamination due to induced saline intrusion or drawing in of contaminated groundwater to the workings; or inadequate control of groundwater rebound leading to ground instability, flooding etc.

Site characterisation is required in order to identify potential impacts and subsequent mitigation measures. Appropriate monitoring is required prior to, during and post dewatering operations so that predicted impacts can be gauged and adequacy of mitigation measures assessed. A range of possible hydrogeological scenarios and engineering solutions for dewatering are reviewed in the report.

The principles of sustainable development can be applied at either the strategic planning level (site selection, need for minerals and potential for use of secondary/recycled materials) or at the site-specific level (design and control measures). Indicators are necessary for the measurement of the progress towards sustainability. Broad sustainable development indicators (SDIs) have been identified by the DETR (DETR, 1999) and these have been adapted for use in assessment of sub-water table quarries and ranked according to their significance (Fundamental, Significant or Minor).

The various scenarios detailed in the report were assessed in terms of sustainability using the SDIs and a weighting system. It was found that, in terms of

- restoration of sun- water table quarries, dry restorations requiring indefinite pumping were likely to be least sustainable, where as wet restorations resulted in less impact,

- geology and hydrogeology, quarries in low permeability strata were generally more environmentally sustainable than those in high permeability strata, except where barriers can be used to control groundwater,

- engineering controls, up-gradient passive systems such as barriers, groundwater cut-offs and deep surface water drains were significantly more sustainable than wells and pumped cut-offs. Long term *complex* water management systems (such as indefinite pumping) are likely to place an impractical burden on future generations,

- method of extraction, wet extraction is more environmentally sustainable than dry, however, there may be planning constraints that override the water resources issues.

This assessment has then been used to develop recommendations for strategic policy under the headings; preferred characteristic/technique; detailed consideration and review required; and presumption against.

1 INTRODUCTION

Quarrying and mineral extraction in the UK is carried out in a wide range of geological and hydrogeological environments. These can range from shallow excavations in unconsolidated deposits such as sands and gravels, to very deep and almost vertical-sided quarries in 'hard' rocks such as Carboniferous Limestone or granite.

Whilst mineral extraction can usually, at least in part, be carried out in relatively dry conditions above the water table, in the majority situations winnable mineral reserves extend beneath the water table and hence many workings are likely to encounter groundwater at some stage in their operation. Consequently these operations have the potential to impact upon the quality, levels and flow regime of groundwater and surface water resources.

In general terms, the deeper and more extensive the quarry, the greater is the likely requirement for water management, and the greater is the potential for adverse impact on water resources. Whilst measures can be incorporated to mitigate adverse effects, other factors, such as the need for, and benefits of, deepening, rather than extending a quarry laterally, may result in impacts for which adequate mitigation may not be possible.

The hydrogeological characteristics of a quarry or mineral workings will dictate the options available where groundwater control is required. For example, a clay pit may require minimal water management, whilst limestone and sandstone quarries may require effective management of large quantities of groundwater. In the latter scenario, development of deep quarries in strata classified as Major Aquifers provides the potential for problems, since, by definition, these aquifers are the most transmissive and have the greatest value in water resources terms. Pumping of large volumes of groundwater from an aquifer over a period of several years, in order to facilitate mineral extraction, is unlikely to represent a sustainable use of water resources.

The Environment Agency (then the National Rivers Authority) first published its 'Policy and Practice for the Protection of Groundwater' in 1992 (Environment Agency, 1998). The policy replaced various groundwater protection policies inherited by the NRA from the former water authorities. One of its objectives was to persuade other bodies, particularly planning authorities, to incorporate proper safeguards for groundwater in their decisions. A series of policy statements was produced relating to a range of human activities that have the potential to put groundwater at risk, in terms of either quality or yield, or both. The policies and principles provide a framework for site-specific decision making using a nationally consistent basis.

In relation to this report, the policy statement addressing 'physical disturbance of aquifers and groundwater flow' is relevant. It indicates that mineral extraction would be acceptable if the site operations could demonstrate that otherwise adverse effects of extraction, de-watering and restoration could be mitigated by measures enforceable by planning controls.

Whilst the policy was revised in 1998, other legislative changes and Agency guidance have placed further emphasis on the importance of protecting and conserving groundwater and surface water resources. However, pumping of water is currently permitted without the need for an abstraction licence under the Water Resources Act 1991, if this is to prevent interference with surface and underground mining, or to prevent damage to works resulting from such operations. Whilst the Environment Agency may serve a Conservation Notice on the operator in these circumstances, to conserve water resources, they do not have the measure of control afforded by an abstraction licence.

In addition to other statutory functions, the Environment Agency has responsibilities and a role in relation to sustainable development in England and Wales. These are set out in Section 4 of Part I of the Environment Act 1995 (DoE, 1995).

> *"It shall be the principal aim of the Agency…….. to protect or enhance the environment, taken as a whole, as to make the contribution towards attaining the objective of achieving sustainable development".*

The Environment Agency is aware of increasing pressure to authorise the development, or deepening of, quarries below the water table. This report has been prepared to consider the issues that come into play in considering such proposals, in order to provide guidance on the implications for water resource protection of quarrying below the water table. It is intended to assist policy development and consistent regulation, and to promote environmentally sustainable quarrying practices, with particular reference to water resources.

This report is arranged as:

- a review of existing guidance and legislation and a summary of findings of a survey of sub-water table quarrying;
- a review of options and methods used for groundwater control;
- implications of groundwater control options for sustainability, and guidance on issues to be considered by operators and regulators in considering development of sub-water table quarries in a range of hydrogeological environments;
- development of a range of indicators of sustainability appropriate to sub-water table sites, and their application to the hydrogeological regimes and engineering options identified; and,
- development of guidance factors for strategic issues in quarry location and planning, taking into account the sustainability indicators derived.

2 LEGISLATIVE FRAMEWORK

2.1 Current and Proposed Legislation and Guidance

2.1.1 Introduction

Minerals development in England and Wales has been subject to an evolving range of legislative controls, a number of which relate to the protection of surface water and groundwater resources. This chapter reviews current legislation and guidance, identifying where possible its applicability to sub-water table quarries. Where further legislation or guidance is proposed, this is identified in order to provide a comprehensive overview of the current and likely future position.

The main areas of legislative control in England and Wales relating to quarry developments are:

1. The town & country planning system, which controls the development and use of land in the public interest, and has the major function of site location;
2. Environmental protection legislation, incorporating measures to protect water resources;
3. Regulations and statutory controls to protect health and safety, and to ensure necessary standards of operations and construction.
4. Government guidance in the form of Planning Policy Guidance notes and other Good Practice Guides, published by the Department for Environment, Food and Rural Affairs (DEFRA) and its predecessor departments, and Policy Guidance notes (published by the Environment Agency).

The main Acts, Regulations, and Guidance associated with 1), 2) and 4) above are presented in Table 2.1, and key elements are summarised in the following sections. This report refers to legislation in England and Wales - legislation in Scotland and Northern Ireland is different, and the appropriate regulatory body should be referred to for guidance.

2.2 EU Directives

2.2.1 EC Directive 85/337. The assessment of the effects of certain public and private projects on the environment

Under the provision of the European Communities Act of 1972, Directive 85/337 is the controlling document, laying down rules for environmental impact assessment (EIA) in Member States. According to the Directive, an EIA is required for two classes of project, one mandatory (Annex I) and one discretionary (Annex II).

EC Directive 85/337 was amended by Directive 97/11/EC.

Table 2.1 : Main Legislation and Guidance Relating to Quarry Development (England and Wales)

Planning	
Acts and Regulations Town & Country Planning Act 1990 / Town and Country Planning (Scotland) Act 1972 Planning & Compensation Act 1991 Town & Country Planning Act (General Permitted Development) Order 1995 / Town & Country Planning (General Development Procedure) Order 1995 / Town & Country Planning (General Development Procedure) (Scotland) order 1992 / Town & Country Planning (General Permitted Development) (Scotland) order 1992, as amended Town & Country Planning (Assessment of Environmental Effects) Regulations 1988 / The Environmental Assessment (Scotland) Regulations 1988 (as amended) Town & County Planning (Environmental Impact Assessment) Regulations (England & Wales) 1999	***Guidance*** DoE Circular 15/88 Environmental Assessment 1988/SDD Circular 12/1988 Environmental Assessment PPG23 Planning and Pollution Control 1994 PPG10 Planning and Waste Management 1999 MPG7 The Reclamation of Mineral Workings DETR Circular 02/99 Environmental Impact Assessment 1999
Environmental Protection	
Acts and Regulations Environmental Protection Act 1990 Water Resources Act 1991 Water Industry Act 1991 Environmental Protection (Duty of Care) Regulations 1991 Control of Pollution (Amendment) Act 1989 Conservation (Natural Habitats) Regulations 1994 Groundwater Regulations 1998 Pollution Prevention and Control Regulations (2000) ***EU Directives*** The Assessment of the Effects of Certain Public and Private Projects on the Environment (85/337/EEC) Groundwater Directive (80/68/EEC) Integrated Pollution, Prevention and Control (IPPC) (96/61/EC) Conservation of Wild Birds (79/409/EEC) Conservation of Natural Habitats and of wild flora and fauna (92/43/EEC)	***Guidance*** Environment Agency Policy and Practice for the Protection of Groundwater 1998 Groundwater Protection Strategy for Scotland DETR Reducing the Effects of Surface Mineral Workings on the Water Environment

A developer is required to prepare an Environmental Statement that includes the information specified by the relevant Member States interpretation of Annex III and to submit it to the competent authority.

Annex III lists matters which must be considered in an EIA including:

- Characteristics of projects: size, cumulative impacts on natural resources, production of waste, pollution and nuisance;
- Location of projects and their characteristics;
- Characteristics of the potential impacts.

In the UK, EC Directive 85/337 is implemented through over forty different regulations. In England and Wales most of the developments listed in Annexes I and II fall under the remit of the planning system. Consequently they are covered by the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988, as consolidated by the subsequent Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999.

2.2.2 Groundwater Directive (80/68/EEC)

The Groundwater Directive prohibits the direct or indirect discharge of List I substances into groundwater and requires that discharges of List II substances are minimsed to prevent groundwater pollution. Authorisation for discharges or disposal activities can only be granted after ‘prior investigation’ has established that pollution of groundwater will not occur, and the Agency is satisfied that ‘requisite surveillance of the groundwater’ is in place. There are a number of relaxations within the Directive, two of which have the effects of allowing a discharge of List I substances to groundwater if the discharge is reintroduction of water pumped out of mines or quarries, abstracted for civil engineering works and the discharge is into the same aquifer. This may be relevant in the case of water abstracted to de-water a quarry.

The Groundwater Directive is transposed in the UK by the Groundwater Regulations (1998) and the Waste Management Licensing Regulations (1994): Regulation 15.

2.2.3 Water Framework Directive (2000/60/EC)

The Water Framework Directive requires member states to manage their water environment in an integrated manner, both in terms of surface and groundwater quality and resources, and groundwater and surface waters. There is a requirement to manage water resources, and specifically groundwater bodies, in order to protect the aquatic environment and dependent ecosystems as a whole. Objectives of the directive include ensuring groundwater meets the criteria of being of ‘good groundwater status’ and that water levels are managed to maintain the ecological health of the surface waters it supports.

Quarrying activities could represent a significant environmental pressure to the water bodies within which they are located. Environmental management of quarries will need to address the requirements of the Water Framework Directive in the future.

2.2.4 Integrated Pollution Prevention and Control (IPPC) Directive (96/61/EC)

IPPC employs an integrated approach to the control of the environmental impacts of a range of industrial sectors. Defined activities can only be operated under a PPC permit issued by the relevant regulatory body. The cement and lime industries, which are classified as Part A1 installations, are due to be implemented under the Pollution Prevention and Control (PPC) Regulations during 2001. However, in terms of quarry development and associated de-watering, these activities are likely to be classified as Part B installations, and regulated by the Environment Agency.

Directives 79/409/EEC on the conservation of wild birds, and 92/43/EEC on the conservation of natural habitats and of wild flora and fauna are likely to be significant if any mineral workings have the potential to affect nature conservation sites.

2.3 UK Acts

2.3.1 The Planning System

National planning legislation is set out in the Town and Country Planning Act 1990 (DoE, 1990) as amended by the Planning and Compensation Act 1991 (DoE, 1991). Many developments may pose a direct or indirect threat to groundwater resources. Where planning permission is required for mineral extraction or industrial development, often the only control is by means of conditions on the permission document, or an obligation (agreement or undertaking) under Section 106 of the Act, or by refusal of planning permission. It is therefore important to recognise developments that may give rise to a potential risk to groundwater or surface water resources.

Planning control is exercised through the local planning authorities, who are required to determine whether the proposed development is an acceptable use of land, rather than the control of the process or substances involved. There are many other relevant controls on water issues that lie outside the scoping of planning legislation. Environmental legislation provides mechanisms to restrict the extent to which any form of development (including surface mineral working and related after-use) is permitted to affect groundwater and/or surface water. The DETR publication “Reducing the effects of surface mineral workings on the Water Environment: A Guide to Good Practice” provides a summary of the planning and legislative background and examines the roles of both mineral planning authorities and the Environment Agency in exerting this control.

The Planning and Compensation Act 1991 introduced a plan led system whereby regional guidance is issued by the Department of the Environment (now DEFRA). Structure Plans and Mineral Local Plans are prepared by County Councils and other Local plans are produced by District Authorities. In addition, with more recent government reorganisation, Unitary Authorities have been created in parts of England and the whole of Wales. The Unitary Authorities differ in approach- some continue to follow a two-tier plan system, and others have embraced all issues within one Plan.

The primary environmental legislation attached to planning control is the Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999 which consolidate all the existing Regulations which implement the requirements of Council Directive 85/337/EEC for projects which are “development”. It will fall to local planning authorities in the first instance to consider whether a proposed development requires an

Environmental Impact Assessment. This is discussed further in section 2.3.2.

In England and Wales, the Environment Agency is a statutory consultee on development plans and many aspects of development control and this includes Environmental Assessments submitted in support of planning applications. The Planning Authority must consider the Agency's views unless that Authority can justify why it's the Agency's requirements should not to be included. In addition to placing conditions on planning permissions, local authorities have powers under Section 106 of the Town and Country Planning Act 1990 to enter into agreement with any person who has interest in land in their area. This power is widely used by planning authorities for the purpose of restricting or regulating the development or use of that land. This is widely used in conjunction with provisions relating to obligations under the Planning and Compensation Act 1991.

2.3.2 Environmental Protection Legislation and Guidance

Introduction

The Environment Agency in England and Wales has a duty to monitor and protect controlled waters. It seeks to ensure the quality and volumes of groundwater resources are protected. It does this by using its own powers and through statutory and non-statutory consultation with other regulatory bodies.

The EC Directive on the Protection of Groundwater Against Pollution Caused by Certain Dangerous Substances (80/68/EEC) defines pollution (of groundwater) as *"the discharge by man, directly or indirectly, of substances or energy into groundwater, the results of which are such as to endanger human health or water supplies, harm living resources and the aquatic ecosystem, or interfere with other legitimate uses of water".* The Directive is implemented into UK legislation by the Groundwater Regulations 1998 (including PPC Regulations) and the Waste Management Licensing Regs 1994. It prohibits the discharge to groundwater of List I substances and limits the discharge of List II substances in order to avoid pollution.

The government's guidance on the Groundwater Regulations is provided in statutory guidance, issued February 2001. The main legislative provisions implementing the protection of groundwater in England and Wales are outlined below.

Other environmental legislation provides mechanisms to restrict the extent to which any form of development (including surface mineral working and related after-use) is permitted to affect groundwater and/or surface water, including:

Environmental Protection Act 1990

Water Resources Act 1991

Water Industry Act 1991

Environmental Protection (Duty of Care) Regulations 1991

Land Drainage Act 1994

Environment Act 1995

Of these, the Water Resources Act 1991 is the most significant with respect to mineral extraction beneath the water table.

2.3.3 Water Resources Act 1991

The Water Resources Act 1991 consolidates all the provisions of the Water Resources Act 1963 in respect of the control of abstraction from groundwater. The Environment Agency has a duty under the Water Resources Act 1991 to monitor and protect the quality of controlled waters which includes ground waters (section 82-84), and to conserve its use for water resources (section 19 and 20.).

This duty includes the control of discharges to controlled waters and powers of pollution prevention (S161A), to prosecute after pollution events (S85), and to take remedial action when pollution has occurred (S161A). These powers have recently been extended by the Anti-pollution Works Regulations 1999.

In respect of groundwater yield and quantity these powers and duties are to conserve water resources and ensure their proper use; manage groundwater; control abstraction of groundwater through the abstraction licensing process; enforce against illegal abstraction; take action to redistribute or augment resources where necessary.

The Agency as a statutory consultee under the planning acts can influence planning decisions that may have an impact on the yield or quality of groundwater. This is an important responsibility that serves to prevent the misuse of water resources occurring, particularly when applied to the development of Structure and Local Plan Policies.

The Agency has the power to control direct discharge of all 'trade and sewage effluents' into controlled waters under Part III of the Water Resources Act 1991. However there are some instances where some indirect discharges of non-trade or sewage effluent cannot be controlled. The de-watering of mines, quarries and engineering works are currently exempt from control. However discharges from these activities require consents under the Act, unless the discharge is from an abandoned mine. Recent guidance from the DETR (DETR, 2000) (now DEFRA) has clarified the role of the Groundwater Regulations in relation to discharges from mines and quarries.

Of particular relevance to surface mineral extraction below the water table is Section 29 of the Water Resources Act 1991, which permits the pumping of water without the need for an abstraction licence, insofar as the abstraction is to *"prevent interference with any mining, quarrying, engineering, building or other operations (whether underground or on the surface); or to prevent damage to works resulting from such operations".* Wells, boreholes or other work (for example a collection sump in a quarry floor), and installed machinery or other apparatus, can also be extended or modified under this exemption for the purposes of abstracting water.

However section 30 of Water Resources Act 1991 requires abstractors claiming exemption rights under section 29 to notify the Environment Agency where de-watering works are to be constructed or extended. It is a criminal offence not to do so. Upon receipt of such a notice the Environment Agency may then serve a Conservation Notice requiring the mineral operator to take reasonable measures for conserving water. This requirement may be attached to the planning permission as a 'planning informative' requiring that a mineral operator notifies the

Environment Agency of their intention to dewater a site.

The Environment Agency has been concerned for some time that exemption of de-watering abstractions is unsatisfactory and inconsistent with the effective management and protection of groundwater resources. New legislation is proposed that will regulate de-watering activities. It is proposed that all abstractions above a small threshold quantity will require prior authorisation, for whatever purpose. The proposed threshold is 20m^3/day and means that few de-watering works will be exempted. The intention is to prevent the new consenting procedure from delaying de-watering works, provided that good practice is proposed and that the site is not environmentally sensitive.

The new regulations are likely to mean that it is essential that those responsible for the planning, design and operation of de-watering and groundwater control works inform the Environment Agency at an early stage, so that appropriate consultation and liaison can take place.

2.4 UK Regulations

2.4.1 The Town and Country Planning Act (Assessment of Environmental Effects) Regulations 1988

The Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999

The Town and Country Planning Act (Assessment of Environmental Effects) Regulations 1988 for England and Wales implements the EC Directive on “The Assessment of the Effects of Certain Public and Private Projects on the Environment” (85/337/EEC, as amended by Directive 97/11/EC). These have a requirement for environmental impact assessments to be carried out in support of new minerals, waste disposal and reclamation schemes.

The subsequent Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999 consolidate all the existing Regulations which implement the requirements of Council Directive 85/337/EEC for projects which are "development". It falls to local planning authorities in the first instance to consider whether a proposed development requires an environmental impact assessment (EIA). Minerals developments are defined as Schedule 2 developments which require EIA if they are likely to have significant effects on the environment by virtue of factors such as its nature, size or location.

DETR Circular 02/99 titled “Environmental Impact Assessment” states that the indicative criteria for identification of Schedule 2 development requiring an EIA is likely to be where the site would cover more than 15 hectares or involve the extraction of more than 30,000 tonnes of mineral per year. However significant effect may also be associated with the consequence of the development upon the water environment.

The significance of a project’s environmental effects is determined on the basis of three criteria:

- Whether the project is of more than local importance, principally in terms of physical scale;
- Whether the project is intended for a particularly sensitive location;

- Whether the project is thought likely to give rise to particularly complex or adverse effects, for example, in terms of the discharge of pollutants.

Regulation 3 prohibits the granting of planning permission for a Schedule 2 development which is likely to have significant environmental effects, unless the EIA procedures have been followed, i.e. an Environmental Statement is provided to be considered with the planning application. Consideration of environmental effects requires mineral planning authorities to consider the likely impact of the development on the environment and the Environment Agency is a consultee in this process.

The Environment Agency has produced scoping guidance notes to encourage a consistent approach to scoping an EIA. Scoping is a crucial part of the environmental assessment process, which helps to identify key issues at an early stage, primarily through consultation with interested parties. The handbook is discussed further in section 2.5.5.

2.4.2 Groundwater Regulations 1998

These Regulations complete the implementation of the EC Groundwater Directive. They deal with measures to prevent the introduction into groundwater of List I substances and limit the introduction of List II substances. The Regulations require requisite surveillance of groundwater and the keeping of an inventory of authorisations for discharges of substances in List I and II.

Statutory guidance issued by DETR (DETR, 2001), (paragraphs 75 and 76) indicates that in addition to the powers to control discharges of water from mines under the Water Resources Act, any discharge to groundwater that contains listed substances comes within the scope of the Groundwater Regulations. In addition, any disposal or tipping for the purposes of disposal, of spoil from mineral workings that contains listed substances also comes within the scope of the Regulations. The Environment Agency has powers (under s19) to prohibit, or place conditions upon, mining or quarrying if it could result in indirect discharges of listed substances to groundwater. In practice this would be achieved by the serving of a notice (conditional or prohibition) on the operator and this would be in addition to the normal planning controls relating to mineral workings.

Thus, though spoil and quarry wastes fall outside of the definition of controlled waste, and are therefore not controlled through the waste management licensing regime, they can be controlled through the Groundwater Regulations where there is a risk to groundwater from listed substances.

The Regulations also allow for statutory Codes of Practice to be introduced for the purposes of the Regulations. These are for the purposes of giving practical guidance to persons engaged in any activity about the steps they should take to prevent substances in List I from entering groundwater or to avoid pollution of such water by substances in List II. At present the only code that may be relevant to mineral workings is the draft code for “Petrol Stations and Other Fuel Dispensing Facilities involving Underground Storage Tanks”.

2.4.3 Conservation (Natural Habitats) Regulations 1994

These regulations must be taken into account when quarry development, or any associated de-watering, has the potential to impact on local habitats, conservation sites or ecology. They transpose the requirements of the Council Directives on Habitats (92/43) and Wild Birds (79/409) and require the designation of Special Areas for Conservation (SACs) under the Habitats Directive. They require all statutory bodies to use their nature conservation powers to secure the requirements of the Directives.

2.5 UK Guidance

2.5.1 Department of the Environment, Circular No. 25/85: Mineral Workings – Legal Aspects Relating to Restoration of Sites with a High Water Table (DoE, 1985)

Circular 25/85 provides guidance to mineral planning authorities in dealing with applications for mineral workings in areas that have a high natural water table. This document outlines the options available in determining planning applications in such areas. The outcome of the application depends on the individual circumstances. The Circular discusses six options for determining planning applications for mineral extraction sites, the sixth being "to permit extraction, leaving the restored level of the site below the water table, but requiring the site to be adequately drained by pumping on a continuous basis". This option is known as "low-level restoration" and is discussed in detail in the Circular.

The Circular outlines that sub-water table restoration needs to be considered prior to granting permission. It identifies the need for restoration and aftercare. However, it also states that the period of aftercare should not exceed five years.

This document discusses the legal aspects relating to securing low level restoration. It considers the powers contained within the legislation, the various parties that are involved in the restoration i.e. the Local Planning Authority, the Mineral Operator, and Drainage Authorities. The need for the various parties to reach agreements is also considered within this Circular and advice is given on the likely content of such agreements.

It should be noted that this guidance pre-dates the Environment Act 1995 and the relationship between the guidance and the Agency's duty with respect to sustainable development is unclear.

2.5.2 Planning Policy Guidance

Planning Policy Guidance Notes (PPG) are prepared by the Government, after public consultation, to explain statutory provisions and provide guidance to local authorities and others on policies and the operation of the planning system. A summary of the relevant PPGs are included in Appendix 1.

2.5.3 Minerals Planning Guidance

The Minerals Planning Guidance series published from 1988 onwards, provides guidance on minerals planning issues. Some of the titles in the series apply only to England. However, in the absence of adopted guidance in Wales these are referenced and summarised in Appendix 1.

2.5.4 Waste Management Papers

WMPs provide separate guidance on all aspects of the planning, design, licensing and management of landfilling operations, this includes sites within former mineral operations, and thus these may be relevant when dealing with minerals sites. Additional details are provided in R&D Technical Report P2-173/TR/1, on sub-water table landfilling (Environment Agency, 2001).

2.5.5 Environmental Assessment: Scoping Handbook for Projects, Report by the Environment Agency, April 1996

This handbook has been produced for Environment Agency staff; developers and their consultants; local planning authorities and others promoting and appraising projects and activities which are likely to affect the water environment. Separate guidance notes are available which cover 61 project types with further detailed guidance for 54 of these. These guidance notes include mineral extraction sites. Each scoping guidance note contains a checklist of water related issues which are Environment Agency responsibilities such as water quality and aquatic biology. Revised guidance on scoping the potential environmental impacts of projects is due for publication by the Agency in the near future.

2.5.6 DETR: Reducing the Effects of Surface Mineral Workings on the Water Environment. A Guide to Good Practice (1998) (Thompson, A. *et al*, 1998)

This guide provides a collation of the basic concepts and potential issues associated with the likely impact of surface mineral extraction on the water environment. It provides a detailed review of the basic concepts relating to hydrological and hydrogeological processes, and explains the meaning of most commonly-used terms.

The guide offers advice for mineral operators and mineral planners in order to help them recognise where specialist information and appropriate expert advice is needed in order to address the issues, as and when they arise. It includes consideration of all surface mineral workings including opencast coal extraction, large scale quarrying of sandstone, limestone and chalk, and sand and gravel workings in river floodplains.

The guide provides a review of the planning and legislative background, consideration of the potential effects on the water environment, preventative, mitigation and remediation techniques, and appropriate methods of assessment and monitoring. The essentials of best practice are considered together with commentary on forward planning and development control in relation to site location and mitigation measures which allow mineral extractions to take place, where it is necessary, with minimal adverse impacts on groundwater and surface water conditions.

The precautionary principle may also be applied which may exclude mineral working in a particularly sensitive area. This is noted as being particularly relevant to developments on flood plains or major aquifers.

The guide assumes that dialogue between mineral planners, operators and the Environment Agency / SEPA is strong. However the guide notes, in Paragraph 9.1, that *"... in reviewing the effects of mineral workings on the water environment, and the various mitigation, assessment and monitoring techniques that can be used, no distinctions have yet been made between the types of effect and appropriate levels of response that may be associated with different types of working".*

Chapter 10 states *"the Environment Agency / SEPA, in their role as statutory consultees, are often best-placed to verify both the extent of potential issues relating to the water environment.... and the efficacy of proposed mitigation measures".*

2.6 Environment Agency Policy

2.6.1 Policy and Practice for the Protection of Groundwater (PPPG) 1998 (2nd Edition)

The PPPG sets out the Agency's policies and recommended practices to protect groundwater resources and abstractions. This document is not statutory but has had a wide public consultation and acceptance, and is referenced in DETR guidance.

The PPPG details the Agency's groundwater protection policies including the classification of groundwater vulnerability and provides Statements on Groundwater Protection Policy. The policy is a framework within which the Agency can use both its statutory powers and contribute to the consultation process in a consistent and uniform manner. The Groundwater Vulnerability maps are available for use in liaison with Planning Authorities and other parties. The maps are referenced in PPG12 and PPG23.

There are eight Groundwater Protection Policy Statements. In particular, Policy Statement B deals with *physical disturbance of aquifers and groundwater flow*, and is directly relevant to development of quarries below the water table. Activities noted in the statement as potentially affecting groundwater but outside the powers of the Agency include:

- all forms of groundwater abstraction outside those controlled by abstraction licences;
- quarrying and gravel extraction above and below the water table, whether worked wet, or dry by de-watering;
- mining.

The Agency recognises the economic importance of these activities, and that potential conflicts may arise because the major raw materials of the minerals industry often come from major aquifers. The Agency in its advice to Mineral Planning Authorities will have regard to its duties under the Water Resources Act 1991 to conserve and protect water resources and to preserve, and where appropriate, enhance conservation of the water environment, and as a statutory consultee will make appropriate representations to the determining authority. The Policy includes various policies for reference when dealing with proposals that may physically disturb or harm aquifers and water resources, lower groundwater levels, or impede or intercept groundwater flow.

The Environment Agency proposes to update the PPPG with a Groundwater Strategy in 2002/03.

3 CURRENT SUB-WATER TABLE QUARRYING

In order to review current practices in relation to sub-water table quarrying and mineral extraction, a review of published information was undertaken, and a questionnaire sent to Agency staff. The aim was to identify the range of approaches to sub-water table quarrying adopted in different hydrogeological environments.

"Reducing the Effects of Surface Mineral Workings on the Water Environment – A Guide to Good Practice " (Thompson, A. *et al*, 1998) was published for the DETR in 1998.

This report provides an excellent review of surface mineral working in the UK, and is referenced in this report, rather than repeating relevant sections. It includes, of particular relevance to this study:

- description of working methods, and hydrogeological characteristics;
- potential effects, including those associated with de-watering;
- mitigation and remediation options where de-watering is undertaken; and
- a classification of potential effects based on the hydrogeological and hydrological environment.

Restoration of exhausted mineral extractions is another important element of quarry development that must be considered in assessing long-term impacts. Requirements for restoration are usually now covered within planning permissions. Sites that have been abandoned with no specific restoration or after-use are generally those that have operated under older permissions.

In addition to the more immediate effects of quarry development and any associated de-watering or water management, restoration can have long-term implications for local water resources. The most appropriate restoration option for a site should be considered at an early a stage as possible, ideally as part of the application for mineral extraction. The most common forms of quarry restoration in the UK are:

- ➢ Open water (amenity);
- ➢ Backfilling with overburden/imported fill;
- ➢ Landfill;
- ➢ Low level restoration above or below the natural water table.

3.1 Hydrogeological Characteristics and Relevance to Sub-Water Table Working

The hydrogeological characteristics of different mineral types will dictate the method used for sub-water table working and the potential effects on groundwater and surface water.

Different methods of mineral extraction are used for different rock types. However, in all situations there is likely to be potential for impacts on groundwater and surface water. Information required to assess potential impacts includes:

- permitted depth of working;
- depth below the water table;
- proposed groundwater control (de-watering) method;
- rate and period of pumping;
- discharge/disposal options;
- local hydrogeological and hydrological characteristics.

For mineral workings, a summary of hydrogeological characteristics of the main rock types, and working methods, follows.

3.1.1 Glacio-Fluvial Sands and Gravels

These deposits can vary greatly in thickness but generally comprise materials of medium-high permeability. In upland areas, free-draining deposits may be unsaturated and therefore require no de-watering. In most lowland areas and in upland areas where there are perched water tables above glacial clays, mineral extraction can require working at considerable depths below the water table. This usually requires de-watering by pumping, but in some cases the sands and gravels can be obtained by dredging from pontoons.

3.1.2 Fluvial Sands and Gravels

These deposits are usually restricted to the floodplains and adjoining terraces of major river valleys. The typically limited thickness of these sediments results in shallow and wide excavations within these moderate-high permeability deposits.

With sites often located within floodplains and on lower river terraces, it is often necessary to work below the water table, although depths may be quite small. De-watering in these circumstances needs to be considered carefully, since pumping adjacent to a river may induce very high rates of inflow, and pumping from a major aquifer may have widespread drawdown effects.

Sub-water table working can be facilitated without de-watering by dredging the mineral from pontoons, or by using a dragline. Wet working can help to limit the impact on local groundwater resources.

3.1.3 Sandstone

Permeability within sandstones is variable, depending on the degree of induration and fracturing. Groundwater flow is both intergranular and via fissures. Some sandstones, such as the Sherwood Sandstone Group are classified as major aquifers, mainly as a consequence of their high permeability and large storage capacity. Other sandstones, such as Carboniferous sandstones or Devonian Old Red Sandstone are classified as minor aquifers, usually as a consequence of poorer water quality, lower permeability or storage capacity.

Many sandstone quarries are deep as a result of the geological units that they work being thick sequences. Working below the water table generally requires large-scale de-watering, usually from a sump in the lowest part of the quarry. Alternatively, groundwater can be controlled by well-point systems around the perimeter of the site.

Many worked out sandstone quarries have in the past been simply abandoned. A proportion of these may be conserved as a consequence of geological or ecological significance. Some have been used for landfilling, although there is generally a preference for infilling of the quarry to above the water table with inert materials prior to landfill development in what are generally sensitive locations.

3.1.4 Coal

Sandstones within the Coal Measures strata provide the main horizons for groundwater flow. They are generally minor aquifers, and groundwater flow is usually via fissures, though mining activities can result in exceptionally high permeabilities. Groundwater quality in these sandstones is often poor as a result of mineralisation in adjacent beds or migration of contaminated mine waters.

Opencast mining below the water table is generally facilitated by de-watering from a sump at an appropriate low point in the workings. Pumping at a high rate may be required to obtain the requisite drawdown, particularly if the site is underlain by deeper coal workings that may allow preferential groundwater pathways into the opencast quarry. Groundwater quality may be a key issue in such quarries.

Reclamation of quarries of this type is often made easier by the typically large volumes of overburden available to backfill the void to near original ground levels. This mode of restoration may modify the local groundwater recharge process, since the original stratified nature of these deposits will have been altered. Landfilling is another common method for restoration of opencast operations, often requiring some backfilling prior to landfill construction so that the landfill base is above the natural water table.

3.1.5 Limestone and Dolomite

Limestones are usually highly permeable, with groundwater flow through fissures which may be large and well connected. In some areas, solution – widening of joints, bedding planes and fractures have formed cave systems and karstic flow characteristics. In these circumstances, and where fissuring is well developed, the limestones are classified as major aquifers. Elsewhere, they may be important minor aquifers.

Quarries of these rock types comprise some of the deepest in the UK, occasionally up to 100m deep. More recent permissions have often limited the depth of working, reflecting concern over the potential adverse impacts of large-scale de-watering. However, most limestone quarries in the UK do not extend beneath the summer water table, often because it is difficult and expensive to achieve the necessary groundwater control in such high permeability strata, although they may extend beneath the winter water table (i.e. be worked dry during summer).

Where limestone quarrying is undertaken below the water table, natural groundwater levels can be significantly lowered, typically facilitated by pumping from a sump in the base of the quarry. Details of proposed monitoring, control, and means of mitigation against derogation of nearby water features are generally required for new quarry developments.

The size and depth of these quarries, lack of suitable waste materials for in-filling, and their location typically in major aquifers, mean that restoration may be problematical. As a consequence, these sites have often been abandoned, allowed to flood when completed, and sometimes used for leisure or nature conservation after-uses.

3.1.6 Chalk

The Chalk comprises a number of limestone units of different physical and hydrogeological properties. Each of these is generally softer and of higher porosity than other limestones. The Chalk typically exhibits dual porosity (i.e. groundwater flow is both intergranular and via fissures), with different mechanisms dominant in different geological horizons and in different parts of the country. Where fissuring is absent, the permeability of the Chalk may be low. However, overall permeability is generally moderate or high, and groundwater is widely abstracted for public supply from this major aquifer.

As in the case of limestone quarries, most Chalk quarries are above the water table, often because of the high costs associated with large scale de-watering and mitigation works. However, where valuable raw materials justify the costs of de-watering, such as in quarries in the south-east of England that supply the cement industry, large volumes of groundwater are abstracted.

Restoration of large chalk quarries can be difficult because of a lack of material suitable for backfilling. Partial backfilling with overburden or imported materials can raise the level of the quarry above the natural water table, in which case they can be used for industrial, commercial or residential redevelopment. Alternatively, sub-water table workings may, subject to planning considerations, be left as areas of open water.

3.1.7 Igneous and Metamorphic Rocks

Most igneous and metamorphic rock types are classified as non-aquifers. Generally, fissuring is poorly developed, and the degree of interconnection limited. Groundwater flow can take place along joints and fractures, but volumes are generally small.

Quarries of this type are often deep, though often dependent on the type of formation and extent of outcrop. In order to access fresh unweathered rock, permission exists for it is proposed that some quarries extend to very considerable depths below ground level.

Many quarries in these rock types penetrate to depths significantly below the regional water table, and can do so without the need for major de-watering since permeabilities are typically very low, and groundwater inflow is limited. Pumping from a single sump in the deepest part of the quarry, where water collects, can usually facilitate the necessary water removal.

Landfilling is commonly used to restore such quarries, as they are typically in low permeability strata and risks to groundwater are generally low. However appropriate assessment is required for any landfill located below the water table.

3.1.8 Clays

Clays are generally characterised by very low permeability, and classified as non-aquifers. They have a high total porosity, and therefore able to store large volumes of water, but a low effective porosity (drainable pore space), and groundwater flow is often negligible. However, some clays have joints, bedding planes, or fissures (e.g. London Clay and Gault Clay) or subordinate sandstone or limestone beds (e.g. Mercia Mudstone Group and Lias Clays) that can transmit significant volumes of groundwater.

Depths of working in clay pits are variable. Those used to provide the raw materials for brick-making are generally less than 30m deep, whilst China Clay workings, for example, can be much deeper, in some cases more than 100m.

In broad terms, clay workings are unlikely to have major significance for local surface water or groundwater resources and very little de-watering is typically required. As with all quarry developments, however, site specific characteristics must be considered in order to make a valid impact assessment. For example, the clay strata being worked may confine an underlying aquifer, which consequently exerts an upward pressure. This pressure must be taken into account so that clay removal is limited and sufficient is left in situ to more than balance the hydrostatic pressure and prevent disruption to the quarry floor by basal heave. Basal heave is likely to result in increased groundwater seepage into the quarry and may cause structural failures.

The low permeability and natural containment characteristics typical of these deposits often leads to their restoration by landfilling. Appropriate site characterisation is necessary in order to understand fully the implications of such a development below the water table or piezometric level. Landfill engineering should take into account potential groundwater inflows and the possibility of basal heave described above. Abandonment of such quarries generally leads to progressive erosion and failure of slopes and the accumulation of water from groundwater and surface water inputs.

The above rock types cover the vast majority of minerals exploited in quarries in the UK. Key hydrogeological characteristics are summarised in Table 3.1.

3.2 Potential Effects

The potential effects of mineral workings on surface water and groundwater are comprehensively discussed in Thompson *et al*, 1998. In this report, we provide a summary of the effects that are of relevance to these studies, concentrating on the likely effects associated with sub-water table quarrying.

Table 3.1: Hydrogeological Characteristics of Mineral Quarries

Type	Examples	Hydrogeological Characteristics
Sands & Gravels	Thames Valley Gravels Glacio-Fluvial	Major Aquifer – intergranular flow dominant Major/minor Aquifer – intergranular flow dominant
Sandstone	Sherwood Sandstone Carboniferous Sandstone	Major Aquifer – fissure flow dominant. Minor Aquifer – fissure flow dominant
Coal	Carboniferous Coal Measures	Minor Aquifer – fissure flow dominant Potential influence by voids, often poor quality groundwater.
Limestone and dolomite	Magnesian Limestone Carboniferous Limestone	Major Aquifer – fissure flow dominant Major Aquifer – often karstic development
Chalk	Specific type of Limestone	Major Aquifer – variable hydrogeological characteristics Dual permeability – intergranular and fissure flow
Igneous and Metamorphic	Granite Dolomite	Non Aquifer – limited flow along joints or faults.
Clays	London Clay Oxford Clay China Clay	Non Aquifer – minimal intergranular flow; limited flow possible where joints, bedding plains or fissures developed.

The impacts of quarrying below the water table will vary depending on the rock type, and the need for and scale of, de-watering. The removal of mineral deposits below the water table means a loss of groundwater storage, although this would normally involve small volumes of water. In low permeability strata such as igneous rocks or clay pits, any effects are likely to be very small. In more permeable strata, the effects will be greater, but are still likely to be of lesser consequence than the long term de-watering itself.

The most significant impacts of quarrying below the water table are those associated with de-watering. They are summarised in Table 3.2, which also presents common methods used for mitigation. The table indicates that the majority of impacts are generally of greatest significance in sandstone, limestone and chalk aquifers, i.e. major aquifers, where the volumes of groundwater to be managed are largest, and the groundwater resources are most valuable.

In all situations, the local hydrological and hydrogeological regimes must be characterised in sufficient detail, so that impacts can be predicted as accurately as possible, and mitigation measures devised where necessary. Appropriate monitoring will be required prior to, during, and after de-watering operations, so that predicted impacts can be gauged against those measured, and the adequacy of any mitigation measures assessed.

3.3 Enviros Aspinwall Questionnaires

In order to obtain information specific to sub-water table quarries, and to provide site-specific examples of practices in England and Wales, a questionnaire was prepared and distributed to identified Environment Agency staff in area and regional offices. This section summarised their responses.

Questionnaires were sent out in January 2000 to Environment Agency staff, of which responses were received from Southern and Thames Regions and from NE Ridings, Upper Severn, Lower Severn and Lower Trent Areas. In summary, the questionnaire sought to provide information on:

- the number of different quarry types within the region/area;
- the estimated number of quarries with permission to extend below the natural water table;
- the aquifer types the quarries are located on;
- groundwater control measures; and
- views of Agency staff in terms of risk assessments carried out, and operational practices used.

The estimated total number of quarries in operation from the ten areas that returned questionnaires, is at least 342 (Table 3.3). NE Ridings and the Lower Trent areas have a large number of opencast mining and vein mineral quarrying operations, represented by 'other' in the table. Precise numbers cannot be presented since some of the responses expressed the numbers as percentages.

3.3.1 Quarries on Major Aquifers

From the responses received, NE Ridings, Lower Trent and the Thames and Southern Regions have quarrying operations located on major aquifers, limestone, chalk or sandstone. This relates to at least 22 sites, 10 of which are in the Thames Region. There are also approximately 38 sand and gravel quarries in the Thames Region, also classified as major aquifers. The Southern Region reply indicated that 90% of quarrying operations are in major aquifer locations although the number of sites is not identified. Lower Severn and Upper Severn areas do not report any active quarries located on major aquifers.

3.3.2 Quarries on Minor Aquifers

Apart from the Thames Region, where sites are located on both major and minor aquifers, all other sub-water table sand and gravel quarry operations are in strata classified as minor aquifers. In addition, all opencast mines in NE Ridings are located on minor aquifers. The remaining sites are clay or limestone, chalk or sandstone operations.

Table 3.2: Common Effects of De-watering, and Mitigation Measures

Effect	Mitigation	Main Quarry Types Affected
Loss of valuable groundwater resource	Limitation of Depth Recharge to an aquifer (preferably avoiding recirculation) De-watering small areas	Sands and Gravels Sandstones Limestones Chalk
Derogation of abstraction wells	Replacement of well Deepening of well Use pumped water as replacement supply	Sands and Gravels Sandstones Limestones Chalk
Derogation of groundwater-fed streams	Augment flow using pumped water if quality acceptable	Limestones Chalk
Detrimental effects on streams by quarry discharge: - physical damage - flora and fauna - contamination (by suspended solids) - contamination (by mineralised mine waters)	Control and monitoring of discharge quantity and quality Use of settlement lagoons or other treatment methods Isolate sources of suspended solids	All
Impacts on levels of wetlands, lakes, pools.	Augment levels using pumped water	Sands and Gravels Sandstones Limestones
Impacts on flora and fauna in surface water features (as above)	Augment water supply with pumped water if quality satisfactory	Sands and Gravels Sandstones Limestones
Inadequate account of water table rebound (on cessation of de-watering): - flooding - land instability - contamination	Raise ground levels. Continued de-watering Water treatment	Coal Chalk
Modification to groundwater flow regime.	Limited options available	All
Drawing contaminated groundwater into workings (potential constraints on discharge)	Removal of contaminant source Installation of low permeability barrier Additional groundwater control to protect quarry inflow	Sands and Gravels Sandstones Limestones Chalk Coal
Saline Intrusion in 'near-coast' quarries affecting the quarry itself, or groundwater abstractions.	Limitation on depth and rate of pumping Relocation of abstraction well Re-injection of pumped water to form a hydraulic barrier	Sandstones Limestones Chalk
Ground settlement and subsidence.	Limitation on depth and rate of pumping.	All

Table 3.3: Estimated Number of Quarries in Operation

	Hard Rock	Clays	Sand and Gravel	Limestone, Chalk, Sandstone	Other	Total
NE Ridings (A)	0 (0)	5 (2)	20 (15)	15 (5)	30 (30)	70
Upper Severn (A)	7 (1)	5 (0)	11 (3)	4 (3)	2 (0)	29
Lower Trent (A)	10 (Most)	<5 (NK)	many (50%)	34 (7)	>22 (NK)	>66
Lower Severn (A)	2 or 3 (0)	2 (1/2)	10 to 20 (>10)	3 or 4 (0)	0 (0)	17 to 29
Southern (R)	0% (0)	10% (50%)	20% (80%)	70% (50%)	0% (0)	100%
Thames (R)	0 (0)	20 (0)	80 (70)	60 (10)	0 (0)	160
Total (at least)	19	32	121	116	54	342

(Totals in brackets represent estimated number that extend or have permission to extend below the natural water table)

NA	=	not applicable
NK	=	not known
R	=	regional response (Both Thames and Southern incorporate 3 Areas)
A	=	Area response

Of these operational quarries:

- In the order of 45% extend or have permission to extend below the natural water table (excluding Southern Region);
- Nearly two thirds of these sub-water table sites are sand and gravel quarries, with the majority in Thames Region;
- All of NE Ridings opencast mines extend or have permission to extend beneath the water table;
- The remaining sub-water table sites are largely limestone, chalk or sandstone quarries.

3.3.3 Quarries on Non-aquifers

All sub-water table sites identified as located on non-aquifers were hardrock or clay quarrying operations.

Examples of aquifer types of particular concern

The area officers gave several examples of sites that were of concern, including:-

NE Ridings (A) - Chalk, Magnesian Limestone (major aquifer)

Sands and gravel (minor aquifer)

Upper Severn (A) - Sand and Gravel superficial deposits, which support local water supplies and conservation features

Lower Trent (A) - Carboniferous Limestone on Habitat Directive sites (i.e. Peak District, Dales);

Carboniferous/Lower Magnesian Limestones - concerns about effects on nearby watercourses and the unsaturated zone

Lower Severn (A) - Sub-water table quarries are a concern in sand and gravel quarries along the River Avon and River Severn (Habitats Directive site)

Southern (R) - Sub-water table quarries are a concern in the Folkstone Beds, Hythe Beds and on Chalk

Thames (R) - Lower Greensand, Recent sands and gravels

3.3.4 Groundwater Control

Pumping groundwater to watercourse is the most commonly used method of control, followed by pumping to recharge the aquifer, then gravity drainage (Table 3.4). At a large number of sites, however, there is no form of groundwater control. From the information submitted, this is most common in the NE Ridings area and Thames Region where there is no control at 40% (20) and 28% (20) of sub-water table sites respectively. In these instances shallow sand and gravel excavations are worked wet.

Table 3.4: Estimated Number of Sites and Measures for Groundwater Control during Operations

	No control	Pumping to watercourse	Pumping to recharge aquifer	Gravity Drainage	Other	Total Number
NE Ridings (A)	20	10	10	10	unknown	50
Upper Severn (A)	1	6	0	0	0	7
Lower Trent (A)	No measures to control groundwater on sand and gravel dredgings, Pumping to watercourse common in limestone quarries, Pumping to recharge aquifer more common in sandstone quarries, Gravity drainage occasionally used					
Lower Severn (A)	Y	Y	N	Y	N	
Southern (R)	10%	50%	40% (recirculation)	0	0	
Thames (R)	20	39	10	1	0	70

Y/N = indication of control measures in place but no figures available

Few responses were provided to a question relating to long-term control measures, indicating that either the officers did not know what long-term measures had been planned, or if there were any plans.

3.3.5 Conservation Notices

Notices are used by NE Ridings, Southern and Thames Region but only very rarely. The other area officers could not recall using Conservation Notices. It is understood that Conservation Notices have been used more frequently in Anglian region.

3.3.6 Risk Assessments

Qualitative risk assessments appear to be carried out for most quarries on major and minor aquifers. The use of quantitative risk assessments is less common, although Lower Trent, Southern and Thames Regions require such assessments on some sites on major and minor aquifers.

Table 3.5: Risk Assessments

	Use of qualitative risk assessments	**Use of quantitative risk assessments**
NE Ridings (A)	Some on major aquifers (recently), most open cast on minor aquifers	No
Upper Severn (A)	Yes on all 7 sites on minor aquifer	No
Lower Trent (A)	On most major, some on minor/non aquifers	Some on major/minor, none on non-aquifers
Lower Severn (A)	On most major, some minor aquifers	No
Southern (R)	On most major and minor aquifers	Some on major and minor aquifers
Thames (R)	On most major and minor aquifers (quality)	Simple on some major and minor

3.3.7 After-use of Sub-Water Table Quarries

The final usage varies considerably between the different areas and regions. In the Southern and Thames Regions, inert landfilling is the most likely end use. Low level restoration is the next most likely form of restoration. NE Ridings is the exception with almost all sites being restored to non-inert landfills.

Table 3.6: After-Use of Quarries

	Inert Landfill	Non-Inert Landfill	Low-Level Restoration	Not Defined
NE Ridings (A)	20	Almost all	5 or less	No answer
Upper Severn (A)	0	0	6	1
Lower Trent (A)	Few	Occasionally	Many	No answer
Lower Severn (A)	40%	1 or 2	40%	20%
Southern (R)	70%	5%	15%	1%
Thames (R)	40	10	20	0

3.4 Conclusions

The information obtained from the survey of Environment Agency staff must be considered to give only a **limited indication** of the extent and nature of sub-water table quarrying in England and Wales. A more comprehensive picture would require more direct liaison with Environment Agency staff in each area or liaison with quarry operators such that all hydrogeological environments and quarrying operations were included.

From the information we have received it is concluded that:

- approximately half of operational quarries extend below the water table;
- number and types vary considerably in different parts of the country;
- about a third of sub-water table sites are located on major aquifers, although this reflects a large number in sands and gravels in the Thames Region (Thames valley deposits);
- pumping to a watercourse is the most common method of water management during the operational phase of quarries;
- qualitative risk assessments are generally carried out for quarries on major and minor aquifers, but quantitative assessments are less common and restricted to a proportion of major and minor aquifer sites.

4 REVIEW OF HYDRAULIC REGIMES

4.1 Introduction

The development of a sub-water table quarry requires, by definition, consideration of a number of factors that may not be relevant in the case of “above water table” sites. To develop a quarry beneath the natural water table, it is likely that in many situations de-watering will be required. Where this is carried out in low permeability strata such as clays, the requirement for de-watering may be significantly less than in more permeable strata. Mineral abstraction from small depths below the water table e.g. in some sand and gravel deposits, may be achieved without the need for de-watering.

Quarry development should take into account the short, medium and long-term groundwater management requirements. As well as consideration of likely impacts associated with de-watering, the position subsequent to cessation of de-watering, and the level of groundwater rebound should also be taken into account.

The purpose of this Chapter is therefore to:-

- describe a range of hydraulic regimes in relation to sub-water table quarries, taking into account different hydrogeological environments;
- identify and review engineering options for lowering the groundwater for various geological and hydrogeological regimes, to facilitate quarry development below the natural groundwater level.

The Chapter is structured to first outline the hydraulic regimes (geology and hydrogeology) and explain how they can be considered in relation to a range of examples of sub-water table quarry developments. Figures 4.2 – 4.6 are schematic drawings which identify potential benefits and problems associated with quarry operations in a range of hydrogeological environments, and link these with issues for sustainability. The Chapter then sets out the basis for the engineering options for controlling the groundwater table to facilitate quarrying. Table 4.1 summarises the review of engineering options in relation to groundwater conditions, identifying those that are suitable, potentially suitable, or unsuitable in relation to the geological, hydrogeological and engineering circumstances.

Engineering options are categorised as active (pumped) and passive (gravity). Summary Figures 4.7 – 4.11 illustrate the engineering options, identify sites which are suited or not suited to the options, and tabulate the potential ‘benefits’ and the ‘problems’ associated with the options. The influence of engineering measures on the groundwater regime, and short and longer term performance of the engineering options are also commented upon. Associated matters that need to be evaluated as part of any quarrying proposal conclude the Chapter.

4.2 Groundwater Regime

Hydrogeological characteristics of the main rock types quarried in the UK have been described in Chapter 3. Potential effects have also been summarised. For a more comprehensive review of these issues, reference should be made to Thompson, A *et al*, 1998. The following sections provide an introduction to the characterisation of hydraulic regimes associated with sub-water

table quarry development, to provide a link with the consideration of sustainability issues later in the report.

4.2.1 Aquifer Types

As described earlier in Chapter 3, quarries in the UK are developed in a broad range of rock types comprising major, minor and non-aquifer locations.

Aquifers can generally be described as:

- unconfined;
- confined; and
- perched.

Unconfined aquifers are those where the upper surface of the saturated zone forms a water table within the water-bearing stratum. A confined aquifer is bound by an upper (and possibly lower) layer of low permeability strata. A perched aquifer is an unconfined aquifer sitting on a low permeability layer that overlies other water-bearing strata, with separate groundwater levels. A schematic representation is included as Figure 4.1.

Hydraulic regimes described in this chapter generally refer to unconfined and perched aquifers. The piezometric groundwater level in confined aquifers should not need to be lowered to develop a quarry into the confining layer, provided it can be demonstrated that there will be no heave of the remaining confining layer, no significant groundwater pressure on the quarry base, and no significant or unacceptable groundwater seepage through the confining layer.

4.2.2 Conceptual Models for Groundwater Control Options

Many factors need to be taken into account in considering any quarry development. This section discusses the potential implications for the development of a sub-water table (or potentially sub-water table) site, in relation to the hydraulic regimes involved.

To illustrate these, a number of examples are presented which consider a range of quarry development and hydrogeological scenarios, and describe the benefits and problems associated with each:

a) Quarry below ‘water table’ in a low permeability formation e.g. clays (Figure 4.2);

b) Quarry below ‘water table’ in a major or minor aquifer (eg River Valley Sands and Gravels) (Figure 4.3);

c) Quarry below ‘water table’ in a major ‘hard rock’ unconfined aquifer e.g. Carboniferous Limestone (Figure 4.4);

d) Quarry development “through” a perched unconfined aquifer (Figure 4.5);

e) Quarry development within a low permeability formation, overlying a confined aquifer (Figure 4.6).

Each of the scenarios are illustrated and the benefits and potential problems listed. Particular focus is given to identifying issues relating to sustainability, taking into account site restoration. Issues for sustainability have been divided into ‘time-related’ and ‘potential’ (see below). These are developed further in chapter 5, where individual significance is considered and ranked in the context of the overall sustainability of such development. The ranking can be used to assess the relative environmental merits and damage associated with different sub-water table quarry designs.

Time-related issues affect the sustainability of a development through the burdens that they **will** impose on future generations by virtue of being required to continue operating. An example would be the need to pump groundwater to maintain lowered water levels. **Potential issues** relate to the possible future deterioration or sudden failure of systems, and the burdens then imposed by those failures.

With respect to possible mitigation measures identified in this assessment “basic” means simple monitoring of groundwater levels and quality at a small number of points, with no automated equipment requiring maintenance, and simple diesel or electric submersible pumps with basic controls. “Complex” means extensive, possibly automated, monitoring critically interactive with groundwater management systems, which may incorporate multiple and/or sophisticated pumping installations and require frequent and/or sophisticated maintenance. “Average” falls between these extremes.

4.2.3 Groundwater Control by Engineering

Selection of engineering systems to control groundwater level is primarily dependent upon:

- the permeability of the ground;
- the depth of the excavation; and
- the depth of the groundwater in relation to the base of the excavation.

In the majority of cases where quarry development is proposed below the water table, there are a limited number of options by which groundwater can be controlled. In most situations, the depth of working and site location preclude the use of anything other than an actively pumped system to lower groundwater levels. This is most simply carried out by pumping from a sump in the base of the quarry, the location of which will change with time as the quarry develops.

There may be circumstances where pumping may not be required:

- shallow workings (e.g. sand and gravels) from which the mineral can be dredged;
- shallow quarries where the water table is close enough to the surface to allow the installation of passive drainage measures;
- quarries where there is a general lowering of the water table as a consequence of mineral extraction providing there is some natural outlet for groundwater drainage.

In terms of control options for “deep” quarries, the potential for “non-pumping” systems is likely to be limited. However, we have included a selection of possible solutions that might be considered in appropriate circumstances.

Table 4.1, which gives a review of hydraulic regimes, categorises the aquifer types as being of:

a) High permeability;
b) Medium/low permeability;
c) Negligible permeability.

Further classification is made on the basis of:

a) Deep sites, low water table;
b) Deep sites, high water table;
c) Shallow sites, low water table.

In this context, “deep” and “shallow”, “high” and “low” are:

a) shallow site: up to 7m below ground level;
b) low water table: less than 7m above the quarry base;
c) deep site: greater than 15m below ground level;
d) high water table: greater than 15m above the quarry base.

There are of course also effectively ‘medium’ sites, which sit between these extremes and in many cases much deeper sites that will not be able to utilise anything other than a pumped system.

Options for groundwater control engineering are set out and their potential suitability indicated on the matrix in Table 4.1. Engineering options have been categorised into active (pumped) groundwater control and passive (gravity) groundwater control. Passive systems are only normally suitable for above ground and end of valley sites where the groundwater can be intercepted, and controlled under gravity. Active systems are where the groundwater cannot be lowered with a gravity discharge, and must be pumped. In the majority of sub-water table quarries, the latter will be required.

Engineering options illustrated for groundwater control include:

Active: 1. Wells
2. Pumped cut-off drain
Passive: 3. Barrier
4. Gravity open drain
5. Gravity cut-off drain

All of the measures except number (3), a barrier to groundwater flowarrier, lower the water table, and the effects of this de-watering must be assessed. This option also requires a “negligible” permeability strata to key into, and will potentially cause the groundwater level to rise up-gradient. The effect of a rise in groundwater must also be assessed.

It is possible to have a combination of options at a particular site, in which case the suitability, benefits and problems for each option should be reviewed. Details of each of the engineering control options, giving a description, when and where they are suitable for use, and benefits and problems, are summarised in Figures 4.7 - 4.11.

Table 4.1: Potential Engineering Feasibility of Groundwater Control Options

ENGINEERING / GEOLOGY/ HYDROGEOLOGY	Active Groundwater Control		Passive Groundwater Control		
	Wells (Figure 4.7)	Pumped Cut-off Drain (Figure 4.8)	Barrier (1) (Figure 4.9)	Gravity Open Drain (Figure 4.10)	Gravity Cut-off Drain (Figure 4.11)
1. High Permeability					
a) Deep excavation, low water table	●	○			
b) Deep excavation, high water table	●	○			
c) Shallow excavation, low water table	●	●	● (1)	○	●
2. Medium/Low Permeability					
a) Deep excavation, low water table	○	○			
b) Deep excavation, high water table	○	○			
c) Shallow excavation, low water table	○	●	● (1)	○	●
3. Negligible Permeability					
a) Deep excavation, low water table	x	x			
b) Deep excavation, high water table	x	x			
c) Shallow excavation, low water table	x	○	○ (1)	●	○

● Feasible Control Option

○ Potentially Feasible Control Option

x Unsuitable Control Option

Blank, not applicable

Excavation - Shallow, <7m below ground level
Deep, >15m below ground level

Water table - Low, <7m above landfill base
High, >15m above landfill base

(1) Requires underlying low permeability strata

4.2.4 Effects of De-watering

The effects of lowering the water table or creating a barrier to groundwater flow must be evaluated in the short term during quarry development, in the medium term during quarry operation, and in the long term for final afteruse. Common effects have been summarised in Table 3.2. The effects on water quality and quantity must be evaluated for:

a) loss of groundwater resources;

b) derogation of existing or planned groundwater abstraction wells and boreholes;

c) impact on surface watercourses and wetlands;

d) impact on flora and fauna;

e) implications of subsequent water table rebound;

f) spread of contamination from external sources caused by changes in groundwater flow paths;

g) saline intrusion caused by changes in groundwater flow paths;

h) subsidence and settlement caused by falling groundwater levels;

i) derogation of archaeological sites.

A selection of the above are used in an assessment of sustainability indicators in the following chapter.

4.2.5 Short and Long Term Performance of Control Measures

Short and long term performance needs to be appraised for changes in groundwater flow in the strata, and deterioration in the engineered control measures, such as blockage or collapse of drainage systems, or failure of pumps.

A potential concern associated with engineering systems will be blockage. For most quarry operations, water quality will be good and the potential for blockages small. However, even for very low levels of contamination, blockage can occur due to:

- accumulation of particulate matter;
- biological action (e.g. biofouling);
- chemical reaction (e.g. mineral precipitation).

In fine unconsolidated sand and silt materials, and some cemented sedimentary materials, there is a risk that the change in groundwater flow could reduce the permeability of the aquifer and/or block the drainage system (wells, cut-off drains). The risk of blockage of the drainage system can be minimised by careful specification of geotextiles and drainage stone, and including mitigation (e.g. over-sizing pipes) to allow for mineral precipitation or biofouling. Collapse of pipework can be avoided by appropriate design and construction methods.

Mechanical and electrical equipment must be accessible for monitoring, maintenance, and replacement. Pumped de-watering systems can incorporate suction, submersible, positive displacement, eductor/ejector, or air pumps. A short description of each system together with potential problems is given in Table 4.2.

Table 4.2: Pumped De-watering Systems

Pump Type	Description	Potential Problems
1. Suction	Centrifugal pump at ground level with a suction hose. Diesel or electric driven. Used in temporary de-watering applications. Easily accessible.	a) Limited suction head, <7m b) Susceptible to wear c) Generally low efficiency pump
2. Submersible	Variable size, capacity and head, centrifugal pump installed below water table. Electrically driven. Significant range to select from.	a) Effected by stop/go pumping regimes. Cause wear and reduce efficiency b) Flow control by valve, lead to loss of efficiency c) Subject to wear from particulate matter
3. Positive displacement	Ram piston or flexible stator screw pumps. Constant flow irrespective of head. Not normally used in field situations, more industrial use.	a) Yield cannot be controlled by valves b) Subject to wear from particulate matter
4. Eductor / Ejector	Water circulated at high pressure by central pump through a venturi nozzle in the de-watering well, change in pressure sucks in groundwater. No moving parts in de-watering wells, but two pipe system.	a) Precipitation and encrustation downstream of nozzle - require maintenance b) Continuous pumping dependent on security for higher pressure feed
5. Air	Air under pressure circulated through venturi nozzle to cause a suction pressure in the pump and suck in groundwater. Only single moving part. Requires air supply and two pipe system.	a) More expensive capital option b) Continuous pumping dependent on security of air supply

4.3 Associated Matters to be Assessed

Whichever engineering system is being evaluated for groundwater control, the following matters should be assessed:

4.3.1 Land availability

Is there suitable land available around the site and does the applicant have access to it for the construction and maintenance of engineering and monitoring facilities? Engineering facilities beyond the excavation are required for wells, cut-off, barrier and open drain. There must be adequate land for boreholes around all sites for monitoring groundwater, and suitable access for monitoring the boreholes, since these are likely to be required to assess the predicted effects of de-watering.

4.3.2 Impact on Local Water Resources

The Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999 require assessment of the impacts of quarry development on the environment, and in particular the water environment.

The impact assessment for sub-water table quarries must appraise:

- the impact of the quarry on groundwater and the feasibility of operation if the water table is not lowered;
- the impact of the site on groundwater with the water table lowered on both short term and long term bases;
- the extent of de-watering required and water disposal options; and
- the likely impacts listed in section 4.2.4.

An assessment will be required to assess the length of time that the water table will need to be lowered. This is likely to be based on:

- the volume of mineral reserves:
- the rate of mineral extraction; and
- the proposed site restoration and after use.

4.3.3 Groundwater disposal route

A disposal route(s) for collected (pumped and gravity drain) groundwater must be identified for the life of the quarry. The disposal route(s) must be suitable for the range of groundwater flows and quantities calculated for the engineered groundwater management system. Maximum and minimum flows for a range of sensitivities must be modelled. Where groundwater is currently depressed by abstraction, the maximum flow collected should be calculated for groundwater rebound conditions on cessation of abstraction. A disposal route(s) for collected (pumped or gravity drained) groundwater be identified for

- low flow, good water quality;
- low flow, poor water quality (maximum contamination);
- high flow, good water quality; and
- high flow, poor water quality (maximum contamination).

Whilst discharge to a watercourse may be the simplest option for the disposal of pumped groundwater, consideration must be given to:

- effects of this on the watercourse, from water quality and ecological standpoints;
- additional risks of flooding;
- significance of this loss of groundwater resource;
- other options, such as recharge to the aquifer at an appropriate distance from the quarry.

4.3.4 Costs

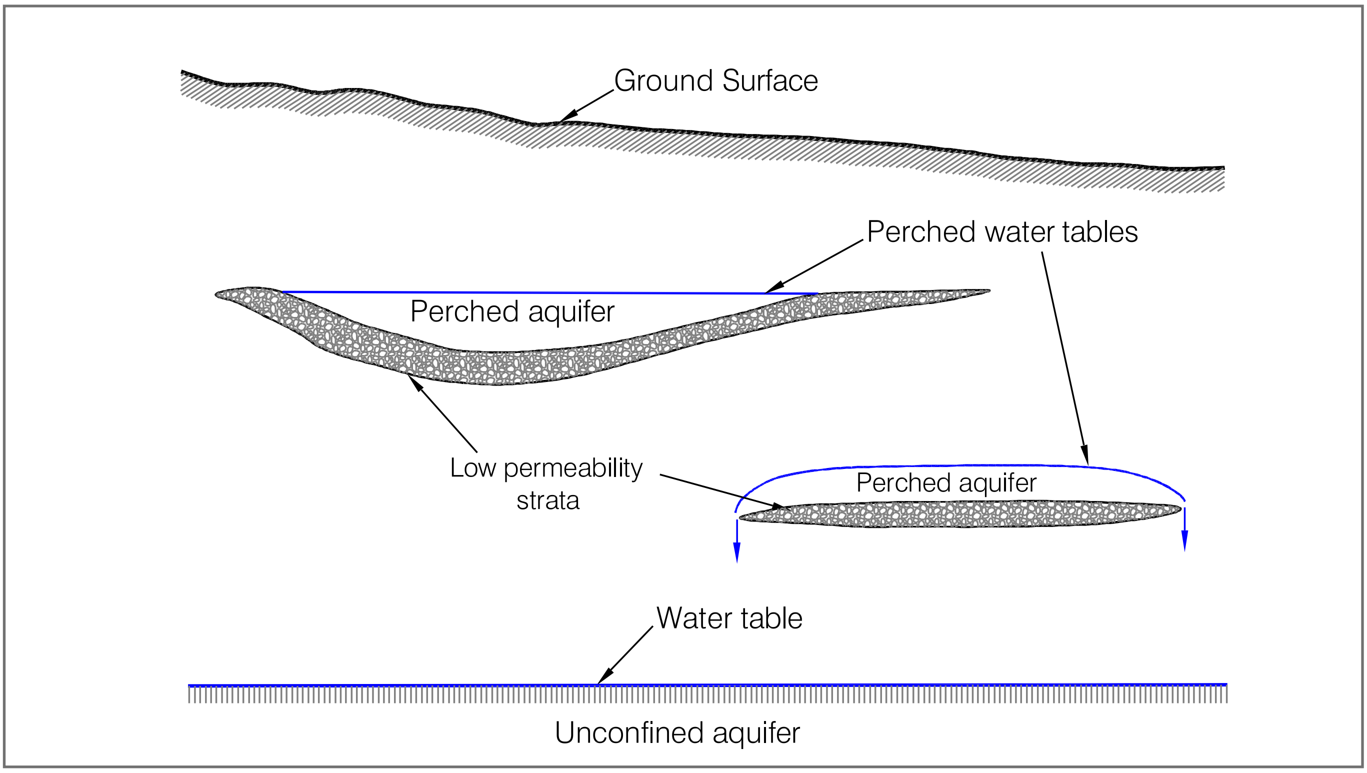
An assessment should be made of the costs and economic viability of a pumped extraction system. As an illustration, if a pumping system's amortised supply and construction cost, and power and maintenance cost are as in the table below, then the overall cost of de-watering at the following rates could be as shown. The net present value (NPV) is the value of the total monetary sum that would have to be allocated now to provide the annual costs required over the specified period. For example, to fund total amortised equipment and running costs of £15000 per year for 50 years (pumping at 86m^3/day), it would be necessary to put aside £272,531 today. This takes account of inflation effects and interest on savings at assumed 5% per annum.

Costs of Pumping (illustration)

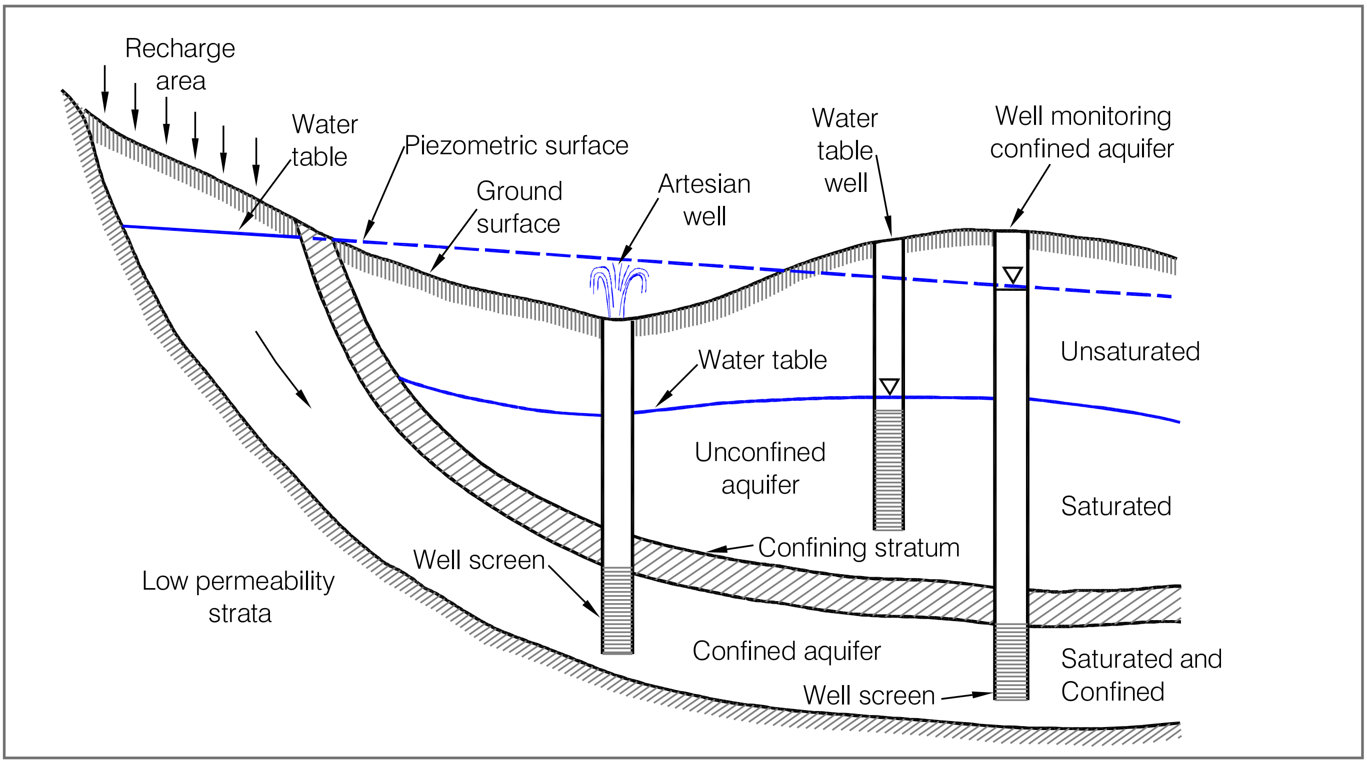
Pump rate (l/s) **(m^3/day)**	**1** **86**	**5** **432**	**10** **864**
Amortised cost per year of pump and equipment (say)	£10,000	£15,000	£20,000
Running Cost per year (say)	£5,000	£7,500	£10,000
Total numerical cost over 50 years	£750,000	£1,125,000	£1,500,000
10 year NPV @ discount rate of 5%	£115,826	£173,739	£231,652
20 year NPV @ discount rate of 5%	£186,933	£280,400	£373,866
30 year NPC @ discount rate of 5%	£230,587	£345,880	£461,174
50 year NPV @ discount rate of 5%	£272,531	£408,796	£545,062

Schematic Representation of Perched, Unconfined and Confined Aquifers

Figure 4.1



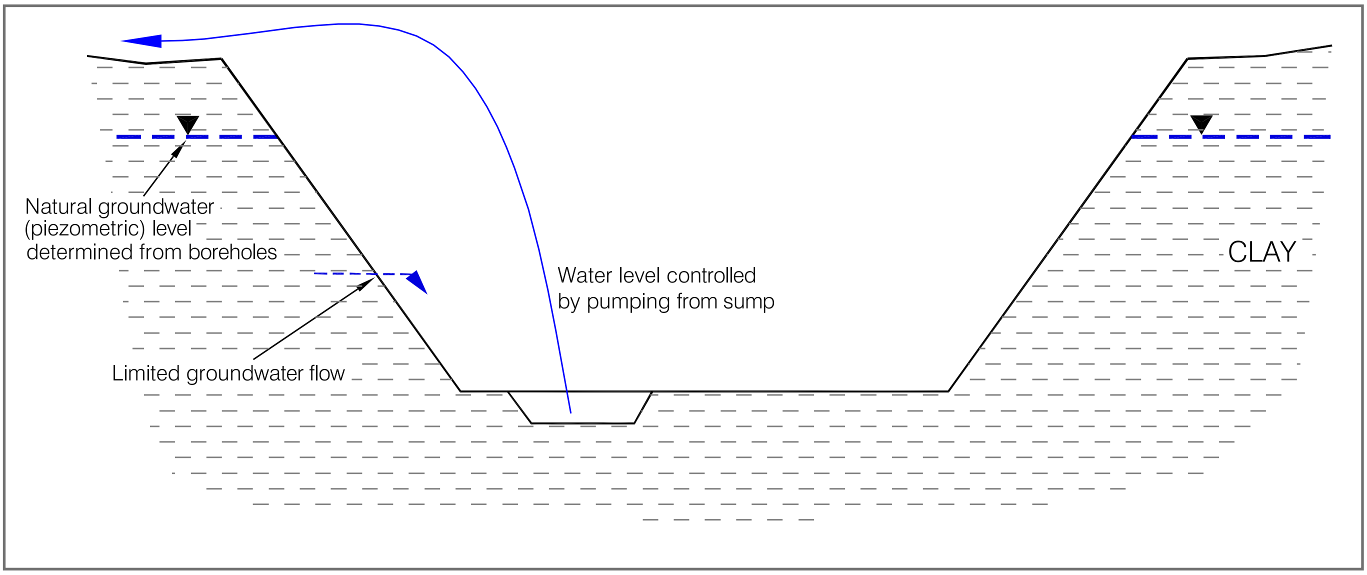
Perched aquifers



Unconfined and confined aquifers

Quarry below 'Water Table' in Low Permeability Formation (e.g. Clay) Figure 4.2

restored wet



Benefits

- Potentially limited groundwater inflow dependent on permeability
- Porewater in clay is unlikely to be exploitable
- Low risk to groundwater (clay is a non-aquifer)
- Low groundwater sensitivity
- Water in final lagoon may be a resource that can be exploited (storage potential)

Problems

- Disruption to original surface water drainage
- Variable pumping rates to receiving watercourse
- Quality of water pumped (eg suspended solids)
    - possible impact on receiving watercourse
- Deterioration in quarry sides due to inflow
- Health and safety
    - steep or unstable sides
    - open water

Issues for sustainability

Time-related

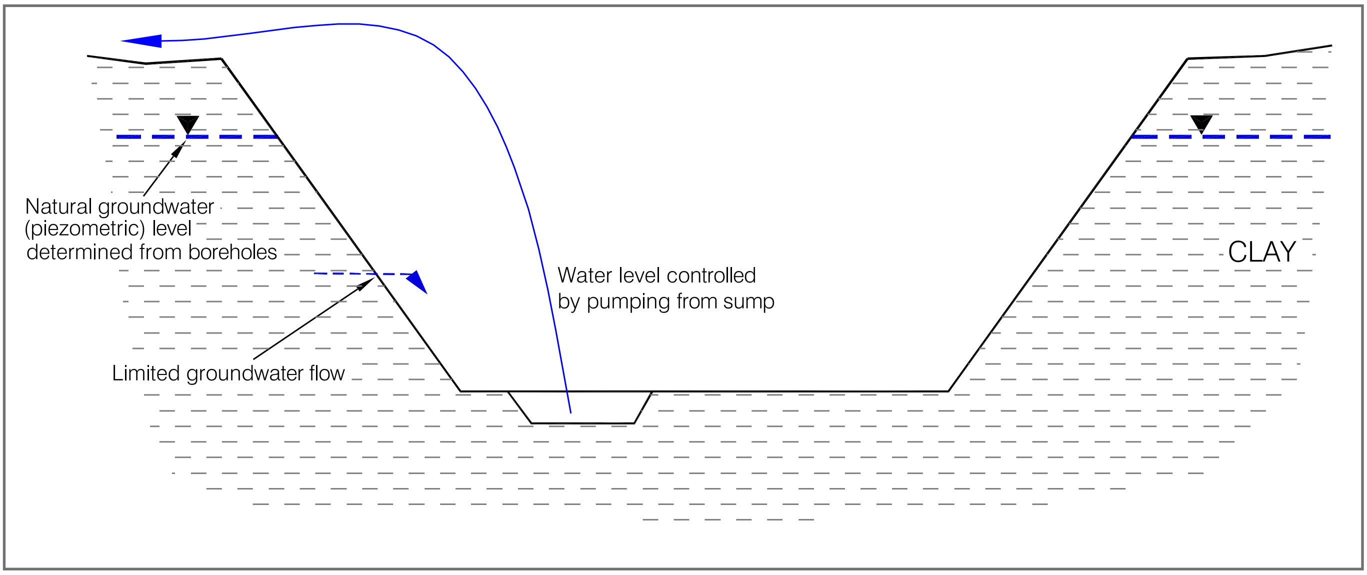
- Medium term pumped water management may be required during operations (basic)
- Monitoring of pumped water required during operations (basic)
- Slow recovery in water levels may delay restoration
- Even wet restoration may require long-term management

Potential

- Variations in water management:
    - level control
    - quality
    - long-term regional level variation
- Potential deterioration in performance of drainage/control measures during operations

Quarry below 'Water Table' in Low Permeability Formation (e.g. Clay) Figure 4.2a

restored dry (low level or landfill)



Benefits

- Potentially limited groundwater inflow during operations dependent on permeability
- Porewater in clay is unlikely to be exploitable
- Low risk to groundwater (clay is a non-aquifer)
- Low groundwater sensitivity
- May be suitable for restoration by landfill (see landfill report)

Problems

- Disruption to original surface water drainage
- Variable pumping rates to receiving watercourses
- Quality of water pumped (eg suspended solids) - possible impacts on receiving watercourses
- Deterioration in quarry sides due to water inflow
- Health and safety:
  - steep or unstable sides during operations

Issues for sustainability

Time-related

- Indefinite pumped water management may be required if low level restoration (basic)
- Indefinite monitoring of pumped water required during operations (basic)
- Restoration may require long-term management

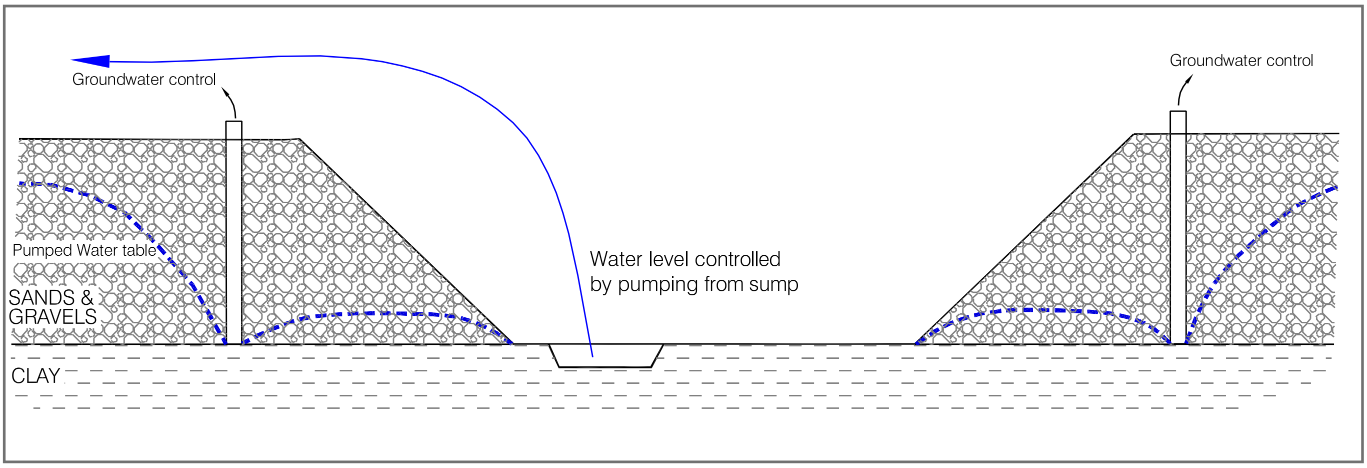
Potential

- Variations in water management:
  - level control
  - quality
  - long-term regional level variation
- Potential deterioration in performance of drainage/control measures

Quarry below Water Table in a Major or Minor Aquifer (eg River Valley Sands and Gravels)

Figure 4.3

dug dry - restored wet



Benefits

- Groundwater controls may assist mineral extraction
- Simple water controls if minor aquifer
- Potentially limited groundwater inflow during operations, especially if minor aquifer
- Discharge may provide alternative supply source (temporary)
- Discharge may allow flow regulation (temporary)
- Water in final lagoon may be a resource that can be exploited (storage potential)

Problems

- Potentially high pumping rate during operations:
    - Impact on groundwater resources
    - Disruption to original surface water drainage
    - Possible impact on receiving watercourses
        - flow rates, and quality
    - Potential for settlement in surrounding ground
- Loss of groundwater resources due to evaporation from open water surface
- Increased groundwater vulnerability
- Potential for induced contaminant intrusion
- Frequently shallow depth/large area of workings
- Health and safety:
    - steep or unstable sides
    - open water

Issues for sustainability

Time-related

- Medium term pumped water management required during operations (basic or average)
- Long-term monitoring of pumped water and groundwater levels and quality required during operations and recovery (basic or average)
- Moderate/high rate of recovery in water levels when extraction complete
- Loss of groundwater resources due to evaporation from open water surface
- Wet restoration requires long-term management

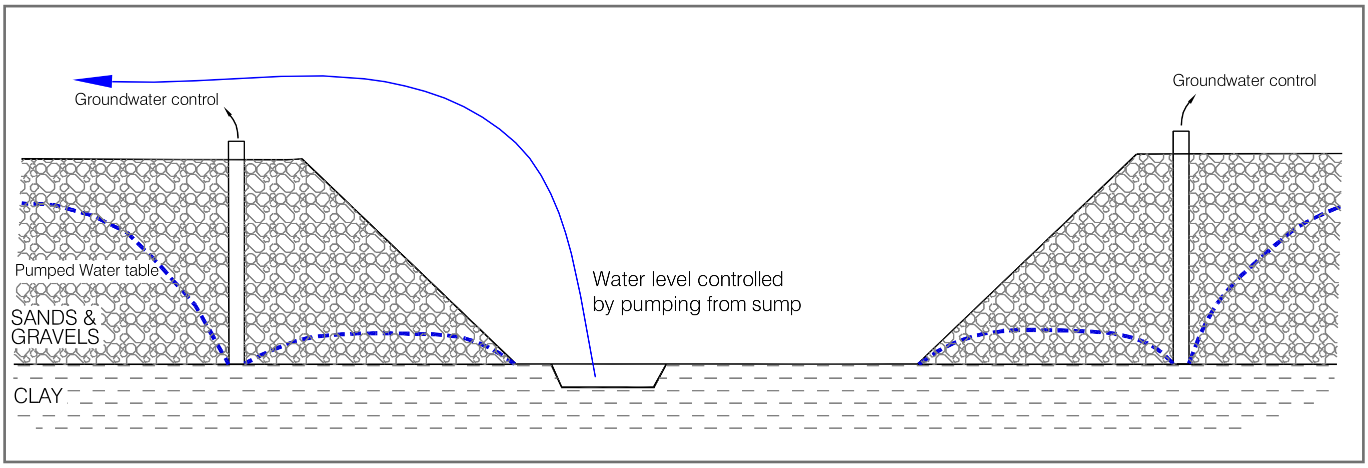
Potential

- Failure of groundwater pumps:
    - water levels rise, hampering operations
    - slippage of sides
- Variations in water management:
    - level control
    - quality
    - long-term regional level variation
- Potential deterioration in performance of drainage/control measures during operations

Quarry below Water Table in a Major or Minor Aquifer (eg River Valley Sands and Gravels)

Figure 4.3a

dug dry - restored dry (low level or landfill)



Benefits

- Groundwater controls may assist mineral extraction
- Simple water controls if minor aquifer
- Potentially limited groundwater inflow, if minor aquifer
- Discharge may provide alternative supply source (but low storage potential)
- Discharge may allow flow regulation

Problems

- Potentially high rate of pumping required long-term:
  - Impact on groundwater resources
  - Disruption to original surface water drainage
  - Possible impact on receiving watercourses
    - flow rates, and quality
  - Potential for settlement in surrounding ground
- Increased groundwater vulnerability
- Potential for induced contaminant intrusion
- Frequently shallow depth/large area of workings
- Health and safety: steep or unstable sides

Issues for sustainability

Time-related

- Potentially indefinite pumped water management required (basic or average)
- Potentially indefinite monitoring of pumped water and groundwater levels and quality required (basic or average)
- Restoration requires long-term management

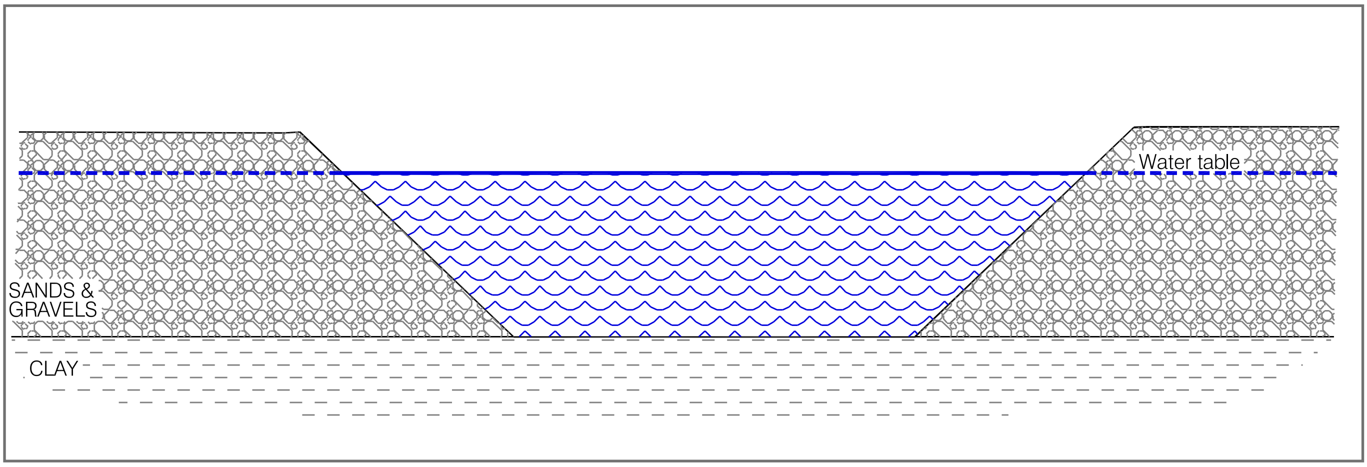
Potential

- Failure of groundwater pumps:
  - moderate/high rate of recovery in water levels, hampering operations and jeopardising restoration
  - slippage of sides
- Variations in water management:
  - level control
  - quality
  - long-term regional level variation
- Potential deterioration in performance of drainage/control measures during operations

Quarry below Water Table in a Major or Minor Aquifer (eg River Valley Sands and Gravels)

Figure 4.3b

dug wet - restored wet



Benefits

- No requirement for pumping of groundwater or surface water
- Simple dragline excavation
- Water in final lagoon may be a resource that can be exploited (storage potential)

Problems

- Possible impact on surrounding groundwater
  - quality/turbidity
  - loss of groundwater resources due to evaporation from open water surface
- Possible impact on adjacent surface water due to turbid runoff
- Excavation depth limited by reach of machines
- Health and safety:
  - steep or unstable sides
  - open water

Issues for sustainability

Time-related

- Long-term monitoring of groundwater levels and quality required during operations (average)
- Frequently shallow depth/large area of workings
- Loss of groundwater resources due to evaporation from open water surface
- Wet restoration requires long-term management

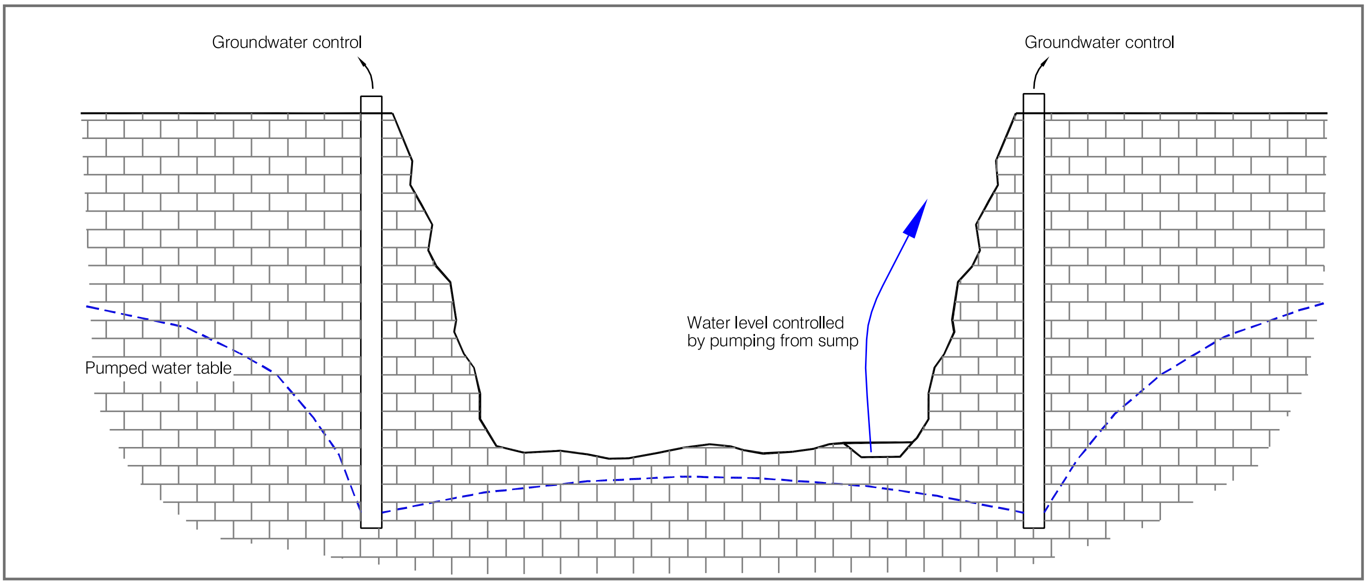
Potential

- Variations in water management:
  - level control
  - quality
  - long-term regional level variation

Quarry below Water Table in a Major Unconfined Aquifer - eg limestone, sandstone

Figure 4.4

dug dry - restored wet



Benefits

- Groundwater controls may assist mineral extraction
- Pumped discharge may provide alternative supply source (temporary)
- Water in final lagoon may be a resource that can be exploited (storage potential)
- Discharge may allow flow regulation (temporary)

Problems

- High pumping rate during operations:
  - Impact on groundwater resources
    - derogation of other abstractions or springs
  - Disruption to original surface water drainage
  - Possible impact on receiving watercourses
    - flow rates and quality
- Loss of groundwater resources due to evaporation from open water surface
- Increased groundwater vulnerability
- Potential for induced contaminant intrusion
- Health and safety:
  - steep or unstable sides
  - open water

Issues for sustainability

Time-related

- Medium term pumped water management required during operations (average)
- Long-term monitoring of pumped water and groundwater levels and quality required during operations and recovery (average)
- Moderate/high rate of recovery in water levels when extraction complete
- Loss of groundwater resources due to evaporation from open water surface
- Long-term management of wet restoration

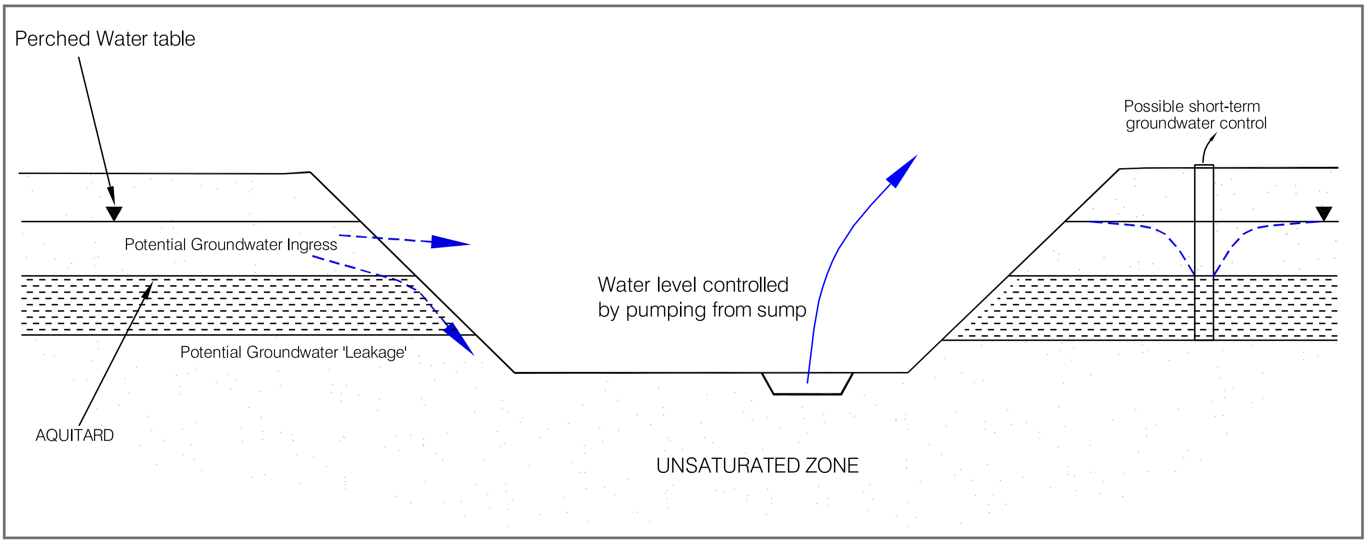
Potential

- Failure of groundwater pumps:
  - water levels rise, hampering operations
- Variations in water management:
  - level control
  - quality
  - long-term regional level variation
- Potential deterioration in performance of drainage/control measures during operations

Quarry Development 'through' a Perched Unconfined Aquifer (eg Lower London Tertiaries)

Figure 4.5

dug dry - restored wet



Benefits

- Potential to "drain" perched aquifer during development period, if permitted, to convert to above water table site
- Potentially limited groundwater inflow during operations from perched aquifer
- May allow managed recharge to underlying aquifer

Problems

- Potentially high pumping rate during operations if there is significant groundwater inflow:
  - Possible loss of groundwater resources (if perched horizon drained)
  - Potential derogation of abstractions and springs fed by perched aquifer
  - Potential impact on ecosystems
  - Disruption to original surface water drainage
  - Possible impact on receiving watercourses
  - flow rates, and quality
  - Potential for settlement in surrounding ground
- Loss of groundwater resources due to evaporation from open water surface
- Increased vulnerability of lower aquifer
- Potential for induced contaminant intrusion
- Health and safety:
  - steep or unstable sides, especially at perched aquifer/aquitard interface
  - open water

Issues for sustainability

Time-related

- Medium-long term pumped water management required during operations (basic or average)
- Long-term monitoring of pumped water and groundwater required during operations and recovery (basic or average)
- Moderate/high rate of recovery in water levels when extraction complete
- Loss of groundwater resources due to evaporation from open water surface
- Long-term management of wet restoration

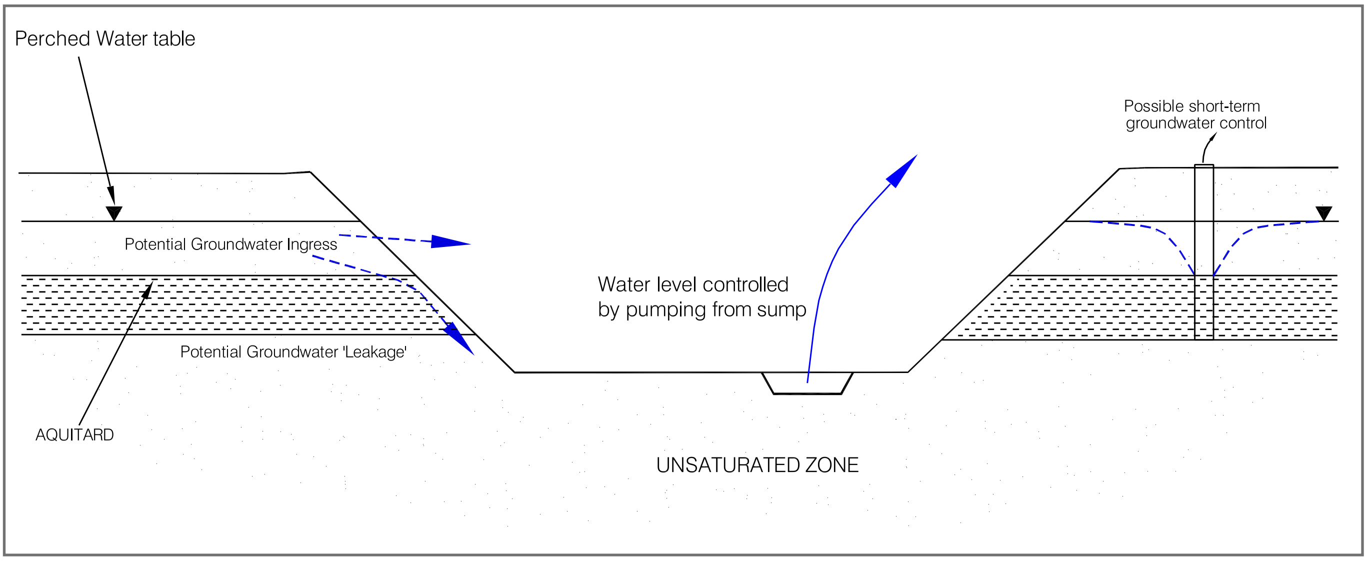
Potential

- Failure of groundwater pumps:
  - water levels rise, hampering operations
  - slippage of sides
- Variations in water management:
  - level control
  - quality
  - long-term regional level variation
- Potential deterioration in performance of drainage/control measures during operations

Quarry Development 'through' a Perched Unconfined Aquifer (eg Lower London Tertiaries)

Figure 4.5a

dug dry - restored dry (low level or landfill)



Benefits

- Potential to "drain" perched aquifer during development period, if permitted, to convert to above water table site
- Potentially limited groundwater inflow during operations from perched aquifer
- May allow managed recharge to underlying aquifer

Problems

- Potentially high long-term pumping rate if there is significant groundwater inflow:
  - Possible loss of groundwater resources (if perched horizon drained)
  - Potential derogation of abstractions and springs fed by perched aquifer
  - Potential impact on ecosystems
  - Disruption to original surface water drainage
  - Possible impact on receiving watercourses
    - flow rates, and quality
  - Potential for settlement in surrounding ground
- Increased vulnerability of lower aquifer
- Potential for induced contaminant intrusion
- Health and safety: steep or unstable sides, especially at perched aquifer/aquitard interface

Issues for sustainability

Time-related

- Potentially indefinite pumped water management required (basic or average)
- Potentially indefinite monitoring of pumped water and groundwater required (basic or average)
- Potentially moderate/high rate of recovery in water levels if pumping ceases
- Long-term management of restoration

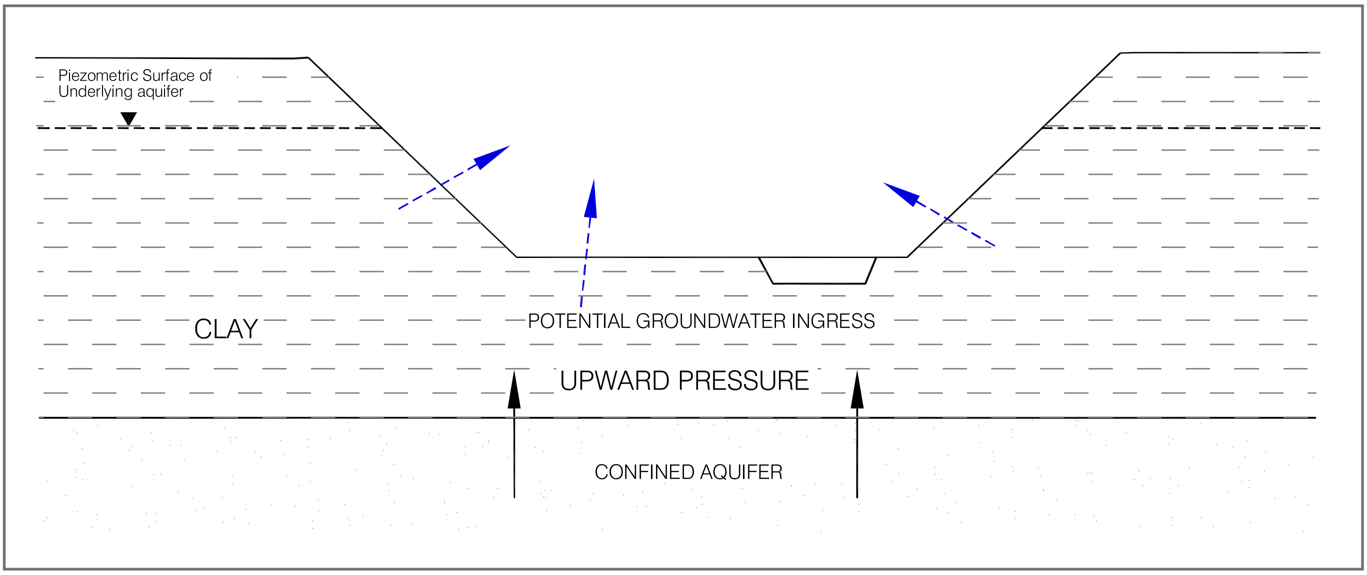
Potential

- Failure of groundwater pumps:
  - water levels rise, hampering operations
  - slippage of sides
- Variations in water management:
  - level control
  - quality
  - long-term regional level variation
- Potential deterioration in performance of drainage/control measures

Quarry Development in a Low Permeability Formation overlying a Confined Aquifer

Figure 4.6

dug dry - restored wet



Benefits

- Potentially limited groundwater inflow during operations from confined aquifer
- Porewater in clay is unlikely to be exploitable
- Water in lagoon may be an exploitable resource (storage potential)
- Low risk to underlying aquifer
- Low groundwater sensitivity
  - little or no impact on groundwater resources
- Limited or no requirement for groundwater control

Problems

- Potentially low pumping rate during operations:
  - Disruption to original surface water drainage
  - Possible impact on receiving watercourses
    - flow rates, and quality
  - Potential for base heave if overexcavated, resulting in significant groundwater ingress
- Health and safety:
  - steep or unstable sides
  - open water

Issues for sustainability

Time-related

- Medium-long term basic water management required
- Long-term monitoring of surface water and groundwater levels and quality required (basic or average)
- Long-term management of restoration

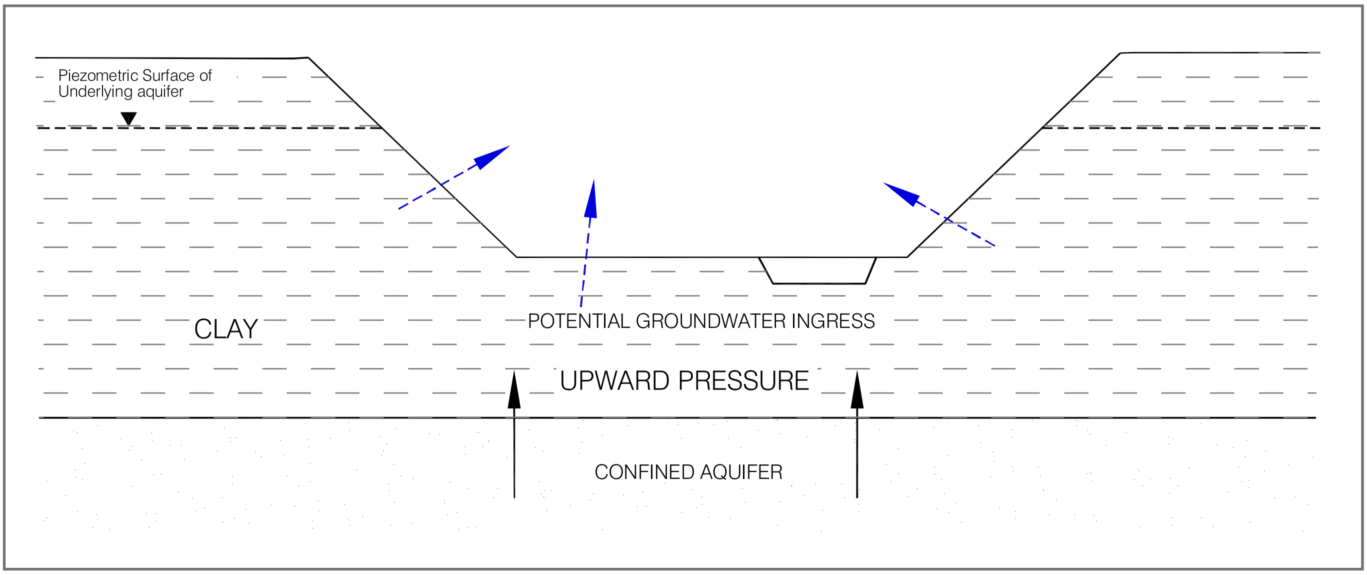
Potential

- Variations in water management:
  - level control
  - quality
  - long-term regional level variation
- Slippage of sides

Quarry Development in a Low Permeability Formation overlying a Confined Aquifer

Figure 4.6a

dug dry - restored dry



Benefits

- Potentially limited groundwater inflow from confined aquifer
- Low risk to underlying aquifer
- Low groundwater sensitivity
  - little or no impact on groundwater resources
- Porewater in clay is unlikely to be exploitable
- Limited or no requirement for groundwater control
- May be suitable for restoration by landfill (see landfill report)

Problems

- Potentially low pumping rate:
  - Disruption to original surface water drainage
  - Possible impact on receiving watercourses
    - flow rates, and quality
  - Potential for base heave if overexcavated, resulting in significant groundwater ingress
- Health and safety: steep or unstable sides

Issues for sustainability

Time-related

- Potentially indefinite term basic water management required
- Potentially indefinite monitoring of surface water and groundwater levels and quality required (basic or average)
- Long-term management of restoration

Potential

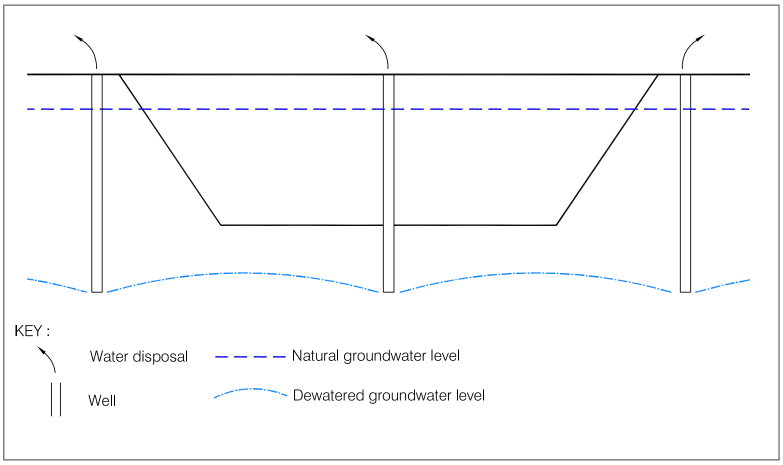
- Variations in water management:
  - level control
  - quality
  - long-term regional level variation
- Slippage of sides

Engineering Measures: 1. Wells

DESCRIPTION

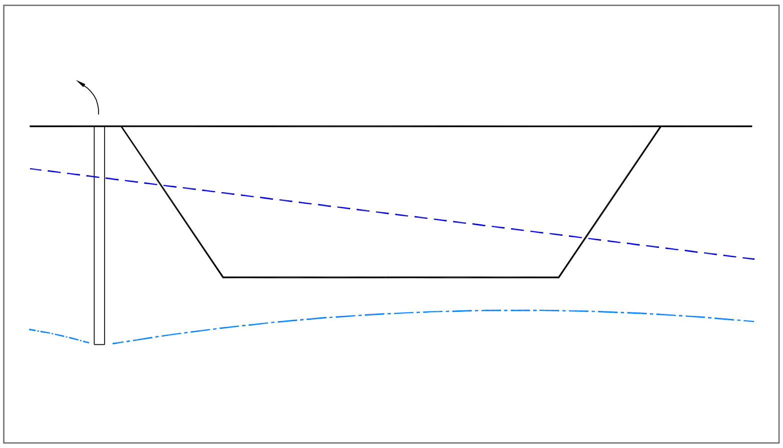
Well Point Dewatering System

A number of wells constructed around the site, each pumped to lower and control the groundwater table below the base of the site:



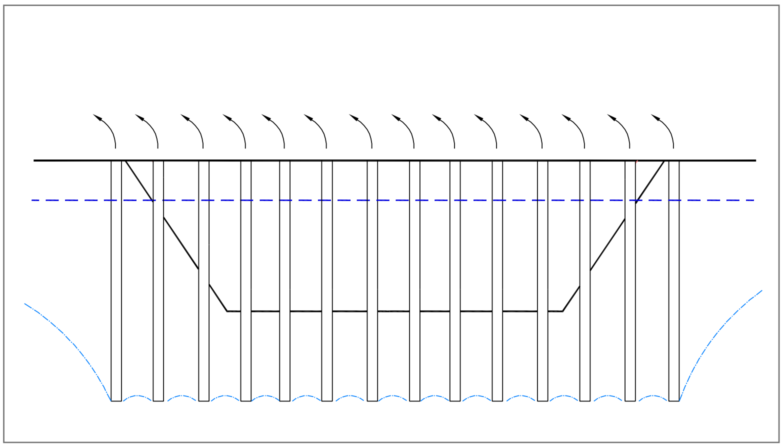
Single Well Point

A well point system could be a single well upgradient of the site, typically in medium permeability, simple, deep strata:



Multiple Well Point

A well point system could be a closely spaced multi-point system, typically in higher permeability, simple, shallow strata:



APPLICATION

Pumped groundwater wells are suited to:

- High & medium permeability fissured and porous aquifers, e.g. chalk, limestone, sandstone;
- Deep sites;
- Homogeneous, simple strata.

Pumped groundwater wells are less suited to:

- Low and negligible permeability strata, where the wells cannot influence the groundwater table beneath the quarry;
- Complex geology;
- Low permeability strata across the base of the site, restricting the depth and effectiveness of the well.

Wells should always be drilled to a depth below the base of the site. Redundancy should be provided such that if a pump fails, there is immediate warning and adequate time to replace it before the water table can rise to the base of the site; or the remaining wells can maintain the groundwater level below the base of the site.

BENEFITS/PROBLEMS

Benefits

1. Wells can be easily replaced;
2. Dewatering equipment can be readily monitored, maintained and replaced;
3. Potentially relatively low capital cost;
4. Can be installed retrospectively at old sites;
5. Suitable for deep sites.

Problems

1. Requires on-going mechanical monitoring and maintenance during operational phase
2. Requires energy supply:
    - revenue cost;
    - burden/resource use;
3. Generally requires more uniform geology;
4. Effect of dewatering on aquifer?
    - possible wasteful use of groundwater resources
    - possible derogation of local abstractions/springs
5. Permeability of the strata around the well and the well could blind in time reducing the radius of influence and effectiveness of the well;
6. Requires land beyond the quarry area for construction;
7. Potential to collect large volumes of groundwater.
8. Require suitable disposal route.

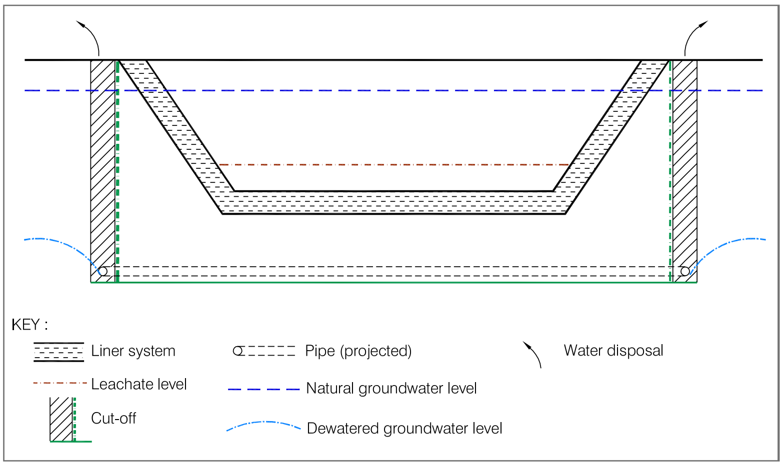
2. Pumped Cut-off Drain

Figure 4.8

DESCRIPTION

A cut-off drain constructed around the site with manholes and a pumped dewatering system to lower and control the groundwater level around the site and aid quarrying operations.

Pumped Cut-off Drain



A cut-off drain may be an excavated trench filled with high permeability non-carboniferous stone, or a geonet fin drain. The cut-off should be constructed below the base of the quarry. The cut-off may be designed with:

- a geomembrane to the quarry boundary in high permeability ground, to provide a permeability contrast. If the ground at/near the base of the quarry consists of low permeability strata, and the geomembrane is keyed into this, then this is effectively a barrier (see Figure 4.10);
- geotextiles to control/prevent blockage by fines in silty/sandy strata.

The location and number of dewatering manholes (points) will depend upon the hydrogeology, size of the site etc.

APPLICATION

Pumped cut-off drains are suited to:

- High and medium permeability strata;
- Shallow sites;
- Drift material;
- Simple and complex geology, including fissured clays

Pumped cut-off drains are less suited to:

- Deep sites (construction practicality and cost);
- Low permeability sites;
- Solid geology (construction difficulties).

Redundancy should be provided such that if a pump fails, there is immediate warning and adequate time to replace it before the water table can rise to the base of the site; the remaining pumps can control the water below the base of the site; or there is a standby pump.

BENEFITS/PROBLEMS

Benefits

1. Dewatering equipment can be readily maintained, monitored and replaced;
2. Not dependent on uniform geology.

Problems

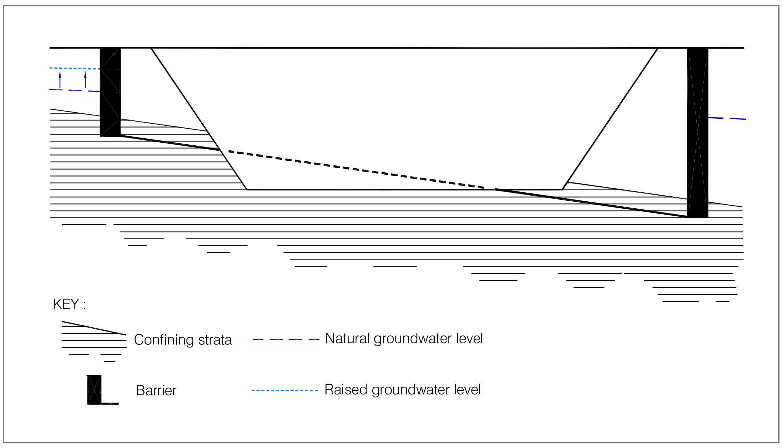
1. Less viable for deep sites;
2. Requires on-going mechanical monitoring and maintenance; moderate burden
3. Requires energy supply:
   - revenue cost;
   - moderate burden.
   - use of resources.
4. Effect of dewatering on aquifer? Potential loss of groundwater resources.
5. Potential for cut-off and pipe to blind with particulates over the life of the site. If this is a risk then redundancy and maintenance should be included in the design;
6. Requires land beyond the quarry excavation for construction;

Figure 4.9

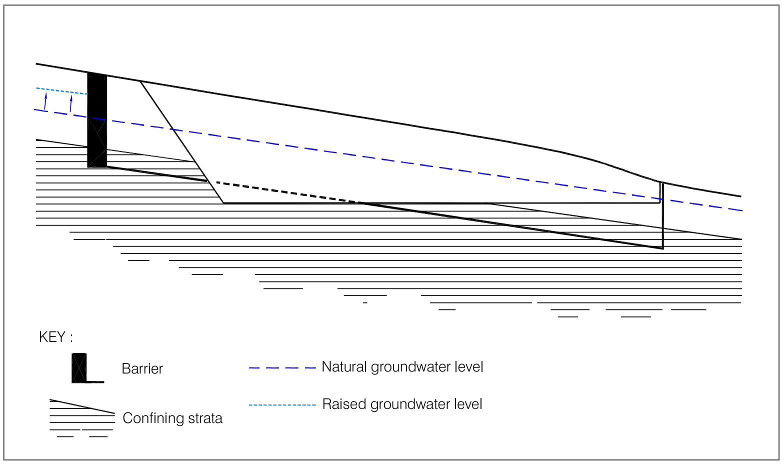
DESCRIPTION

These require a confining layer below and around the site which acts as the barrier and can be keyed into. The barrier will then isolate the site from the groundwater.

Barriers example 1



example 2



Barriers can be:

- excavated, constructed and backfilled e.g. benonite - cement walls with or without geomembranes;
- excavated, installed and backfilled e.g. geomembranes;
- injected, e.g. grouts.

There is less certainty over the performance of grouts. However, they are suited to deeper sites.

APPLICATION

Barriers are normally suited to:

- Shallower sites;
- Drift materials;
- The full range of permeabilities.

Barriers are less suited to:

- Deep sites;
- Solid geology.

BENEFITS/PROBLEMS

Benefits

1. Passive solution:
   - no revenue cost
2. Do not require frequent maintenance;
3. Likely limited impact on groundwater resources;
4. Blinding not a concern;
5 No collected water for disposal;

Problems

1. Requires underlying confining layer;
2. Causes rise in groundwater level upstream and lowering downstream (requires modelling to assess);
3. Difficult to achieve low permeability in construction and durability (some seepage will occur);
4. Requires land beyond the quarry for construction;
5. May not be cost effective;
6. Will interfere with groundwater flow regime.

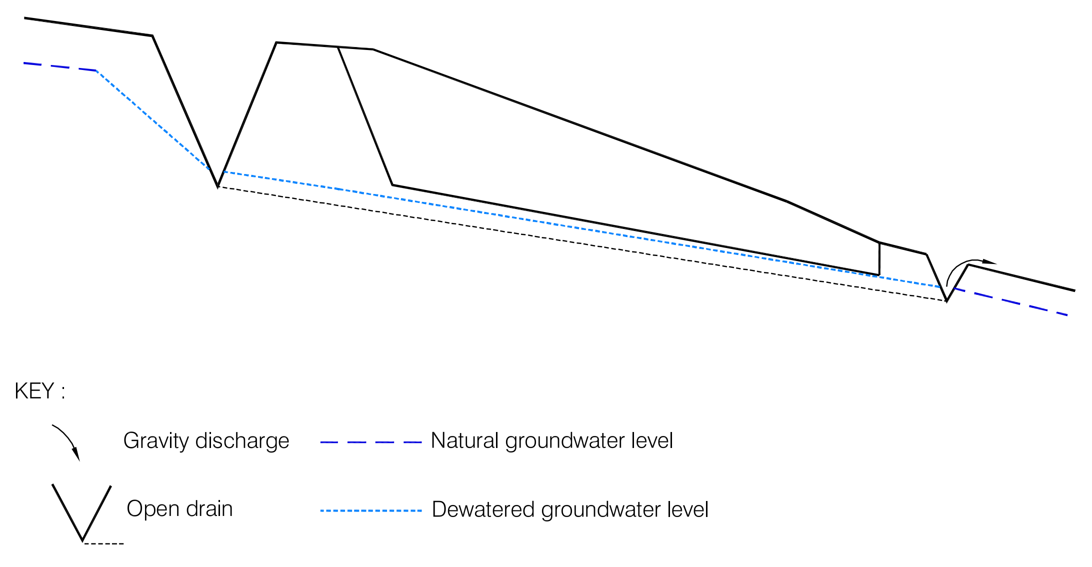
5. Open Drain

Figure 4.10

DESCRIPTION

The construction of a deep ditch around a shallow site that collects groundwater and surface water, and discharges them by gravity, thereby lowering the groundwater table below the base of the site.

Open Drain



APPLICATION

Open drains are suited to:

- Shallow sites;
- Cross fall for gravity drainage outlet;
- Medium and low permeability aquifer;
- Drift material.

An open drain is less suited to:

- Deeper sites;
- High permeability strata;
- Solid materials.

BENEFITS/PROBLEMS

Benefits

1. Passive system:
   - no revenue cost;
2. Low maintenance requirement and cost;
3. Highly robust;
4. Suitable for above ground/steeply sloping sites;
5. Limited impacts on groundwater resources.

Problems

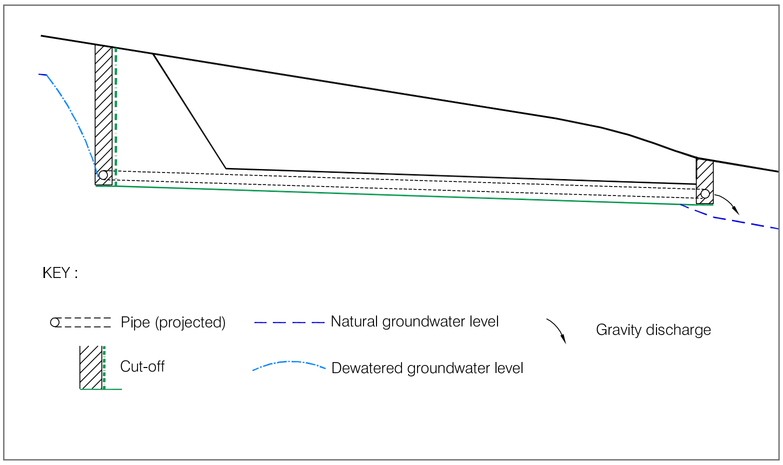
1. Only suited to shallow sites;
2. Require free gravity drainage outlet;
3. Will interfere with groundwater flow regime
4. Impact of gravity drainage needs to be assessed

6. Gravity Cut-off Drain

Figure 4.11

DESCRIPTION

A cut-off drain constructed around the site with gravity discharge to lower and control the groundwater level around the site.



A cut-off drain may be an excavated trench filled with high permeability non-carboniferous stone, or a geonet fin drain. The cut-off should be constructed below the base of the quarry. The cut-off may also be designed with:

- a geomembrane to the quarry boundary in high permeability ground, to provide a permeability contrast. If the ground at/near the base of the quarry comprises low permeability strata, and the geomembrane is keyed into this, then this is effectively a barrier (see Figure 4.9);
- goetextiles to control/prevent blockage by fines in silty /sandy strata.

APPLICATION

Gravity cut-off drains are suited to:

- Shallower sites;
- High and medium permeability aquifers;
- Water bearing non-aquifers eg fissured clays;
- Drift material;
- Simple and complex geology;

Gravity cut-off drains are less suited to:

- Deeper sites (construction practicalities and cost);
- Solid geology (construction difficult).

BENEFITS/PROBLEMS

Benefits

1. Passive system:
   - no revenue cost;
2. Not dependent on uniform geology.
3. Highly robust;
4. Limited impact on groundwater resources.

Problems

1. Requires free gravity outlet;
2. More suited to shallow or steeply sloped sites;
3. More suited to drift materials;
4. Requires careful design to prevent cut-off blinding with fines over life of site;

5 DERIVATION OF SUSTAINABLE DEVELOPMENT INDICATORS FOR SUB-WATER TABLE QUARRIES

5.1 General Principles of Sustainable Development

> *"I know no phrase better designed to create an intellectual constipation than the phrase 'sustainable development'. In my experience people spend endless hours trying to define what they mean by it, when the original Brundtland definition of* ***'development that meets the needs of today without undermining the capacity of future generations to meet their needs'****, is about as good a definition as you need. It is much more important to focus on the practical challenges of sustainable development."*
>
> *Tom Burke, Environmental Adviser to BP Amoco & Rio Tinto: Sustainable Development - The Agenda. Institute of Environmental Management & Assessment, Annual Conference, December 1999*

The government's strategy on sustainability was outlined in the document *Sustainability Counts: Headline Indicators* (DETR, 1998). The four broad objectives of the Government's vision are:

- maintenance of high and stable levels of economic growth and employment;
- social progress which recognises the needs of everyone;
- effective protection of the environment; and
- prudent use of natural resources.

The DETR document *A better quality of life: a strategy for sustainable development for the UK* (DETR, 1999), launched on 17 May 1999, lists 87 proposed Sustainable Development Indicators (SDIs), which are reproduced in Appendix 2.

In December 1999 the UK Government published the first in a promised series of annual assessments of progress towards sustainable development. The report is based on a national set of about 150 indicators, plus a headline set of 15 indicators which is also listed in Appendix 2. A Government website dedicated to sustainability issues, www.sustainabledevelopment.gov.uk, has now been established to provide briefings on progress towards greater sustainability. However, the national set remains essentially unchanged.

5.1.1 Key objectives for Minerals

The key sustainable development objectives for the mineral industry may be described as:

- to conserve minerals as far as possible while ensuring an adequate supply,
- to minimise waste production and to encourage efficient use, and re-use, of materials; and
- to minimise environmental damage from minerals extraction.

MPG 6 (DoE, 1994) notes the need to encourage the efficient use of aggregates and to consider alternative sources, including the use of secondary and recycled materials, as a means of reducing the need to excavate primary aggregates.

The Quarry Products Association (QPA) has developed commitments, which it considers “will provide very real and developable benefits to the countryside and local communities close to quarry operations”. The proposals include the establishment of the Quarry Industry Sustainability Foundation financed by the industry and the production of best practice guidance on Environmental Impact Assessments. These proposals have, however, been affected by the announcement of a tax on virgin aggregates, which the QPA is still resisting.

5.2 Development of Quarries below the Water Table - Principles

The principles of sustainable development may be applied at two levels:

- at the strategic planning level, encompassing the requirements for minerals and aggregates, the potential for production of secondary resources through recycling, and the planning issues associated with site selection; and
- at the site specific level, encompassing the design and control features for the facility.

Together these will determine whether, overall, a planned site meets sustainable development objectives.

The focus of this project is on *guidance for strategic planning on sustainability indicators pertaining to the protection of groundwater, with specific reference to developments below the water table.* However, in defining whether a particular project is the Best Practicable Environment Option (BEPO), sustainability criteria for the project as a whole should also be considered.

A fundamental difference between sub-water table and above water table quarries is in their restoration and after-use. Sub-water table quarries may either be restored “wet”, to some form of fishing, aquaculture or leisure use, or to a “dry” or “low level” use, via diversion or pumping of groundwater as described in Chapter 4. The sustainability of permanently pumped low level restoration must be determined in consideration of the benefits gained through the productivity and use of the land so released. For example, large areas of East Anglia and the Netherlands are maintained in this way. It is probable, however, that sub-water table quarries will generally be left “wet” unless they can be maintained dry by gravity drainage or passive barriers. The following assessment of relative sustainability does not discriminate between the relative planning merit of either type of restoration.

5.2.1 Criteria for Indicators of Sustainable Development

In order to be able to measure progress towards greater sustainability it is necessary to identify indicators that can be monitored, and their rate of change established. This is usually carried out over a period of time, to enable trends to be observed and priorities for change to be identified. For the purposes of developing immediate guidance on the relative environmental sustainability of sub-water table quarry designs, it is necessary first to develop appropriate indicators, and then to consider them against a range of natural and engineering settings, to establish the relative importance of defining factors. These can then be used to determine strategic guidelines to encourage development in those sites with the most favourable (environmental) attributes, using the most sustainable engineering approaches.

Three basic criteria for sustainability are used by the Organisation for Economic Co-operation & Development (OECD) which may be considered to apply more widely, as set out in Table 5.1.

Table 5.1: Criteria for Selecting Environmental Indicators

Policy Relevance	An environmental indicator should: • provide a representative picture of environmental conditions, pressures on the environment or society's responses; • be simple, easy to interpret and able to show trends over time; • be responsible to changes in the environment and related human activities; • provide a basis for international comparisons; • be either national in scope or applicable to regional environmental issues of national significance; • have a threshold or reference value against which to compare it, so that users can assess the significance of the values associated with it.
Analytical Soundness	An environmental indicator should: • be theoretically well founded in technical and scientific terms; • be based on international standards and international consensus about its validity; • lend itself to being linked to economic models, forecasting and information systems.
Measurability	The data required to support the indicator should be: • readily available or made available at a reasonable cost/benefit ratio; • adequately documented and of known quality; • updated at regular intervals in accordance with reliable procedures.
Ref: OECD: Environmental Indicators 1998	

5.2.2 Selection of indicators relevant to sub-water table operations

To derive sustainable development indicators (SDIs) appropriate to the strategic assessment of the suitability of sub-water table quarry designs, it is useful to start with the overall Government SDIs reproduced in Appendix 3. The following sections describe the selection, ranking and, where necessary, expansion of these as appropriate to sub-water table operations. In order to use this assessment to derive key determining factors for sustainability, the SDIs are then applied to the typical sites shown in Figures 4.2 to 4.6, in Section 5.3 and Table 5.7.

In that some of these SDIs are only marginally affected by ***sub**-water table* impacts (cf. **above** water table) a grading system of **F**undamental, **S**ignificant, and **M**inor indicators has been adopted in this review. **This classification is necessarily arbitrary and should be reviewed periodically.** The ranking of F/S/M applies solely and specifically to sub-water table aspects. Therefore, in Table 5.2 the only Fundamental issues are those relating to water demand and abstractions, as these may be substantially affected by de-watering or groundwater barriers.

Other SDIs in Table 5.2 have been generally ranked more highly if water issues are affected.

It should be noted that although from a planning perspective SDIs may be both “good” and “bad”. For example, a downwards extension of a quarry below the water table could be preferable to lateral extension with accompanying increased land take from a planning perspective, but a potential threat to water resources from the Agency’s perspective. In this report, which is written for Agency purposes, the SDIs selected generally represent potential environmental detriment. For the purpose of determining a framework for assessing the relative sustainablility of quarries below the water table all of the SDIs proposed should therefore be taken as “undesirable”.

In the subsequent tables the SDIs are developed into a set of specific indicators focused on the issues relating to sub-water table operations.

Table 5.2: Application of Proposed (DETR 1999) Sustainable Development Indicators (SDIs) to Sub-Water Table Quarries

(F = Fundamental; S = Significant; M = Minor)

SDI No	**SDI**	**Ranking**
1	Secondary aggregate use cf. virgin	(N/A; Planning issue)
2	Land covered by restoration/ aftercare conditions	S
3/4/5/6/12/ 13/50/D13	Species and biodiversity, countryside quality, wild bird populations, landscape features	S (if left flooded)
14	SSSIs	S
15	Nutrients in water	M
17, 30	Contaminants in sea, Dangerous substances in water	M
20	Water demand and availability	F
23	Water abstractions	F
24	Low flow in rivers	F
50/76	Rivers of good or fair quality	S (if left flooded)
79	Access to the countryside	M
D3	Energy/Water consumption	S
K8	Noise levels	M

These indicators of the impacts for sustainable development of sub-water table development may for convenience be grouped into **Key** Indicators, as shown in Table 5.3.

Table 5.3: Derived Key Indicators

Key SDI	**SDI**	**Ranking**
A	Best use of mineral resources	S (but only for planning)
B	Restoration or avoidance of despoiled land	S (but only for planning)
C	Requirements for long-term management, including energy use	F (moderated by relative complexity)
D	Species, biodiversity, landscape, SSSIs, countryside access	S
E	Conservation of surface water, groundwater resource quality	F
F	Conservation of surface water, groundwater resource (quantitative)	F
G	Noise, emissions from additional equipment required	M

These Key Indicators cover the overall sustainability objectives as indicated in Table 5.4, which excludes SDIs A and B for the reasons given.

Table 5.4: Correlation of Proposed Key Sustainable Development Indicators (SDIs) for Sub-Water Table Operations, with Objectives for Sustainability

Key SDI No	**SDI**	**Sustainability Objective**	Maintenance of high and stable levels of economic growth and employment	Social progress which recognises the needs of everyone	Effective protection of the environment	Prudent use of natural resources
C	Requirements for long-term management inc. energy use		?	√	?	?
D	Species, biodiversity, landscape, SSSIs, countryside access			?	√	√
E	Conservation of surface water, groundwater resource quality		?		√	√
F	Conservation of surface water, groundwater resource (quantitative)		?		√	√
G	Noise, emissions from additional equipment required			?	√	

5.2.3 Development of key SDIs for use in comparing sub-water table operations

In order to use SDIs in assessment of the relative sustainability of options for sub-water table quarrying, the Key Indicators A-G given in Table 5.3/5.4 have been developed, as shown in Table 5.5. For ease of application, all Fundamental, Significant, and Minor SDIs are then grouped together in Table 5.6

The degree of sustainability of an indicator is determined by its **effect** in a particular site setting, rather than by its generic application. As previously described, the purpose of this report is to help assessors determine the relative sustainability of sub-water table quarry designs at a strategic planning level. The designation of **F**undamental, **S**ignificant or **M**inor in Table 5.5 therefore indicates the **probable effect** in typical situations, as applied to the scenarios described in Chapter 4.

Possible mitigation measures identified in this assessment have been categorised as "basic", "average" or "complex"; these are described fully in Section 4.2.2.

Where an "indefinite" life of control systems is required, the sustainability depends upon their complexity; for example, simple periodic cleaning of a drainage channel is likely to be more sustainable than the maintenance and periodic replacement of a complex computer-controlled pumping system. This is discussed below, together with comparisons with the sustainability of above water table quarries.

5.3 Application of Derived SDIs to Sub-Water Table Quarries

Each of the typical hydrogeological settings and related quarry designs described in Figures 4.2 to 4.6 indicates both time-related, and potential, issues for sustainability (see 4.2.2). Similar issues are described in Figures 4.7 to 4.11 depicting typical engineering control measures.

In general this report considers only those issues that relate specifically to sub-water table developments. However, there are some issues that apply also to above water table sites but whose impact on sustainability is worsened by sub-water table development.

For each of the SDIs identified in the previous discussion there is a potential correlation with the issues for sustainability identified for each site-type shown on Figures 4.2 to 4.6, and for the control options shown in Figures 4.7 to 4.11. In Table 5.7, correlations are shown as **(3)**, where it is definite, as **(2)** where it is a possibility, or as **(1)** where it is a possibility, but either unlikely to occur, or unlikely to be significant. This "scoring" combines very simplistically *significance* and *probability,* but is considered sufficient to approximate the relative degrees of sustainability for the purposes discussed. The numbers should not be taken to imply that a **(3)** is three times more significant or probable than a **(1).** Both the correlation and the degree of certainty are subjective, as indeed is the classification of Fundamental, Significant, or Minor, but Table 5.7 does provide a broad indication of the relative sustainability of sub-water table quarrying and enables a degree of consistent analysis.

The assessment and "scoring" of Sustainable Development Indicators, site types and engineering measures in Table 5.7 is drawn together and illustrated in Figures 5.1 and 5.2.

These have been produced by plotting the numerical values from Table 5.7, both at “face value” and with a relative weighting of 3 × Fundamental, 2 × Significant, and 1 × Minor.

Table 5.5: Detailed SDIs Relating to Sub-Water Table Operations

Key SDI	SDI	Ranking	
C	Long-term management:	Monitoring: Basic: Average: Complex:	M M S
		Maintenance: Basic: Average: Complex:	M S F
		Pumping: Basic: Average: Complex: Energy use: All:	M S F S
		Longevity of control systems required: Quarry Operations: Quarry Operations plus 30 years: Indefinite:	 M S F
D	Species, biodiversity, landscape, SSSIs, countryside access	Effects of lowered/backed-up groundwater levels: Effects of varied stream flow: Effects of creating open water bodies: *(Planning)*	S S -
E	Conservation of surface water, groundwater resource (quality)	Effects of eutrophication/ sunlight/ siltation: Potential for intrusion of saline or other contamination into intercepted groundwater: Effect of discharged groundwater on receiving surface water:	M S F
F	Conservation of surface water, groundwater resource (quantitative)	Effect of lowering local groundwater level on wider groundwater levels, resource, and stream flows: Effect of barrier to groundwater flow on groundwater levels, and on stream flows: Effect of discharge of groundwater on receiving surface water: Loss of groundwater resource due to evaporation from open water surface: Effect of crating an open-water body (size dependent)	F S F S S
G	Noise, emissions	Sub-water table control de-watering pumps:	M

F - Fundamental M - Minor S - Significant

Table 5.6: Summary of SDIs for Sub-Water Table Operation, by Ranking

Fundamental Sustainable Development Indicators:

Key SDI	SDI	Detail
C	Long-term management:	*Complex* Maintenance
		Complex Pumping
		Indefinite longevity required for control systems
E	Conservation of surface water, groundwater resource (quality)	Effect of discharge of groundwater on receiving surface water
F	Conservation of surface water, groundwater resource (quantitative)	Effect of discharge of groundwater on receiving surface water
F	Conservation of surface water, groundwater resource (quantitative)	Effect of lowering groundwater level local to site, on groundwater levels, available resources, and on surface water flows

Significant Sustainable Development Indicators:

Key SDI	SDI	Detail
C	Long-term management:	*Complex* Monitoring
		Average Maintenance
		Average Pumping
		All Energy uses
		Systems required for *Operations plus 30 yrs*
D	Species, biodiversity, landscape, SSSIs, countryside access	Effects of lowered or backed-up groundwater levels Effects of varied stream flow
E	Conservation of surface water, groundwater resource (quality)	Potential for intrusion of saline or other contamination into intercepted groundwater
F	Conservation of surface water, groundwater resource (quantitative)	Effect of barrier to groundwater flow on groundwater levels and flow, and potentially on surface water flows Loss of groundwater resource due to evaporation from open water surface Effect of creating an open water body

Minor **Sustainable Development Indicators:**

Key SDI	SDI	Detail
C	Long-term management:	*Basic* or *Average* Monitoring
		Basic Maintenance
		Basic Pumping
		Control systems for *Operational period only*
E	Conservation of surface water, groundwater resource (quality)	Increased susceptibility to eutrophication / effects of sunlight / siltation
F	Conservation of surface water, groundwater resource (quantitative)	Loss of groundwater resource due to evaporation from open water surface
G	Noise, emissions	Sub-water table control de-watering pumps

5.3.1 Apparent Trends

From consideration of Table 5.7, and in particular the general relativity shown on the graphs (Figures 5.1 and 5.2), the following broad conclusions can be drawn. (L: low score, i.e. high relative sustainability; M: medium score, moderate relative sustainability; H: high score, low relative sustainability):

Examination of Table 5.7 indicates that the most significant factors affecting relative sustainability in this summation are:

- type of restoration (“dry” or “wet”)
- groundwater vulnerability
- strata permeability
- pumping requirements
- energy use
- maintenance obligations

A further key factor is whether the quarry is excavated “dry” or, as in sand and gravel option 4.3(b), dug wet.

These significant factors can be further developed by reference to Figures 5.1 and 5.2, which indicate the following trends:

Type of Restoration

“Dry” restoration, where the site is restored to a land surface at low level, requires indefinite pumping and maintenance, and gives a high “Fundamental” score.

“Wet” restoration to a lake requires greatly reduced and possibly no long-term pumping and maintenance.

Table 5.7: Site Types: Coincidence of SDIs with Characteristics of Site types

Key: 3: Definitely 2: Possibly 1: Possibly but unlikely to be major **Sustainable Development Indicators:** (relevant to sub-water table aspects)	Landfill in low permeability formation (Fig 4.2)	*Time related issues:*	Long-term simple leachate pumping	Long-term simple monitoring	Waste degradation	*Potential issues:*	Leachate level rise: possible low impact on insensitive g/w	Total "Score"	Landfill in minor/major aquifer with no g/w control (Fig 4.3(i))	*Time related issues:*	Long-term simple leachate pumping	Long-term relatively simple monitoring	Waste degradation	*Potential issues:*	Leachate level rise: possible impact on minor aquifer	Total "Score"	Landfill in minor/major aquifer with g/w control (Fig 4.3(ii))	*Time related issues:*	Long-term simple leachate pumping	Long-term simple groundwater pumping	Long-term relatively simple monitoring	Waste degradation	*Potential issues:*	Failure of groundwater control system: more leachate	Leachate level rise: possible impact on minor aquifer	Total "Score"	Landfill in Major unconfined aquifer with temporary or no groundwater control (Fig 4.4(i))	*Time related issues:*	Groundwater control/ingress while levels balance (Temp)	Long-term moderate leachate pumping	Long-term moderate monitoring	Long-term complex management of levels	Waste degradation	*Potential issues:*	Balance system failure: Possible impact on major aquifer	Total "Score"	Landfill in Major unconfined aquifer with groundwater control (Fig4.4(ii))	*Time related issues:*	Long-term moderate leachate pumping	Long-term reliable groundwater pumping	Long-term moderate monitoring	Waste degradation	*Potential issues:*
Fundamental																																											
Complex Long-term Maintenance								0								0										0				3		3				6							
Complex Long-term Pumping								0								0										0				3						3							
Control systems required long-term								0								0										0						2	2			4						2	
Potential effect of liner seepage on GW quality							1	1							1	1									1	1									2	2							
Potential effect of liner seepage (anticipated or greater) on quality of intercepted GW or /receiving SW								0								0				2						2										0				2			
Effect on GWLs, resource, and SW flows, of lowering groundwater level local to site								0								0				2						2			3							3				3			
Effect of discharge of GW on receiving SW flows								0								0				2						2			3							3				3			
Significant																																											
Complex Long-term Monitoring								0								0										0			3		3	3				9							
Average Long-term Maintenance								0								0										0										0			3	3			
Average Long-term Pumping								0								0								2		2										0			3	3			
All Energy uses								0								0			3	3				2		8				3						3			3	3			
Control systems required for site life plus 30 years					2			2					2			2						2				2										0							
Effects of lowered or backed-up GWLs on biodiversity etc								0	2							2				2						2			2							2				3			
Effects of varied SW flow on biodiversity etc								0								0				2						2										0				3			
Effects on biodiversity etc of removing temporary open water bodies in worked-out quarries	2							2	2							2	2									2	3									3				2			
Potential for intrusion of saline/ contamination on (dewatered) GW								0								0				2						2										0	2						
Effect of barrier to GW flow on GWLs, and potentially on SW flows								0	2							2										0										0							
Minor																																											
Basic or Average long-term monitoring				3				3				3				3					3					3										0					3		
Basic long-term Maintenance				3				3			3					3			3	3						6										0							
Basic long-term Pumping			3					3			3					3			3	1						4										0							
Control systems required for site life only					2			2								0										0			3							3							
Noise, emissions from surface pumps in base of site								0								0			1	1						2				2						2			1	1			
Total "Scores" (sub-water table)	**2**		**3**	**6**	**4**		**1**	**16**	**6**		**6**	**3**	**2**		**1**	**18**	**2**		**10**	**20**	**3**	**2**		**4**	**1**	**42**	**3**		**14**	**11**	**3**	**8**	**2**		**2**	**43**	**2**		**10**	**26**	**3**	**2**	
Total "Scores" (inc. "typical" above water table site)								42								44										68										69							

Table 5.7: Site Types: Coincidence of SDIs with Characteristics of Site types

Key:
3: Definitely
2: Possibly
1: Possibly but unlikely to be major

Sustainable Development Indicators: (relevant to sub-water table aspects)	Failure of groundwater system increases leachate generation	Failure of leachate system increases leakage	Total "Score"	Landfill through perched aquifer with possible g/w control (Fig 4.5)	*Time related issues:*	Long-term simple leachate pumping	Short-term possible groundwater pumping	Long-term simple monitoring	Waste degradation	*Potential issues:*	Increased leachate seepage due to system failure or liner disruption	Total "Score"	Landfill in low permeability formation overlying confined aquifer with no g/w control (Fig 4.6)	*Time-related issues:*	Long-term simple leachate pumping	Long-term simple monitoirng	Waste degradation	*Potential issues:*	Leachate level rise: possible low impact on porewater	Total "Score"	Typical Above-Water Table Landfill	**"Typical" above watertable landfill:** non- hazardous; composite lined; active (pumped) leachate management; active gas management 2m thick unsaturated zone; overlying minor or non-aquifer Sustainability Indicators as below, but also (unquantified) others, including: fugitive gas emissions; traffic; resource consumption
Fundamental																						
Complex Long-term Maintenance			0									0								0	4.5	Average to Complex: Definite and x 1.5
Complex Long-term Pumping			0									0								0		("Scores" x 1.5 because of gas *and* leachate pumping, but allowing for extg leachate pumping in assessment of sub-water table site)
Control systems required long-term			2						2		2	4								0	3	
Potential effect of liner seepage on GW quality		2	2								2	2							1	1	2	
Potential effect of liner seepage (anticipated or greater) on quality of intercepted GW or /receiving SW			2								2	2								0		
Effect on GWLs, resource, and SW flows, of lowering groundwater level local to site			3				1					1								0		
Effect of discharge of GW on receiving SW flows			3				2					2								0		
Significant																						
Complex Long-term Monitoring			0									0								0		
Average Long-term Maintenance			6								2	2								0	4.5	Average to Complex: Definite and x 1.5
Average Long-term Pumping			6								2	2								0	4.5	Average to Complex: Definite and x 1.5
All Energy uses			6				2					2			3					3	4.5	x 1.5
Control systems required for site life plus 30 years			0						3			3					2			2		
Effects of lowered or backed-up GWLs on biodiversity etc			3				1					1								0		
Effects of varied SW flow on biodiversity etc			3									0								0	1	eg, due to pumped discharge of SW from within site
Effects on biodiversity etc of removing temporary open water bodies in worked-out quarries			2	2			1					3	2							2		
Potential for intrusion of saline/ contamination on (dewatered) GW			2				1					1								0		
Effect of barrier to GW flow on GWLs, and potentially on SW flows			0				2					2								0		
Minor																						
Basic or Average long-term monitoring			3					3				3				3				3		
Basic long-term Maintenance			0			3	2					5			3					3		
Basic long-term Pumping			0			3	2					5			3					3		
Control systems required for site life only			0									0								0		
Noise, emissions from surface pumps in base of site			2			2						2			2					2	2	
Total "Scores" (sub-water table)	**0**	**2**	**45**	**2**		**8**	**14**	**3**	**5**		**10**	**42**	**2**		**11**	**3**	**2**		**1**	**19**	**26**	
Total "Scores" (inc. "typical" above water table site)			71									68								45		

Table 5.7: Engineering Measure: Coincidence of SDIs with Engineering control Measures

Key: 3: Definitely 2: Possibly 1: Possibly but unlikely to be major **Sustainable Development Indicators:** (relevant to sub-water table aspects)	Wells (Fig 4.7)	Maintenance	Monitoring	Energy	Derogation of groundwater resource	Increases groundwater levels upgradient	Derogation of surface water resource	Prone to long-term reduction in performance	Potential for contamination by leachate and therefore need to treat large volumes	Inaccessible for repair/replacement	Total "Score"	Pumped Cut-off Drain (Fig 4.8)	Maintenance	Monitoring	Energy	Derogation of groundwater resource	Increases groundwater levels upgradient	Derogation of surface water resource	Prone to long-term reduction in performance	Potential for contamination by leachate and therefore need to treat large volumes	Inaccessible for repair/replacement	Total "Score"
Fundamental																						
Complex Long-term Maintenance		1									1		1								1	2
Complex Long-term Pumping		1									1		1									1
Control systems required long-term	2							1			3	2							1			3
Potential effect of liner seepage on GW quality											0											0
Potential effect of liner seepage (anticipated or greater) on quality of intercepted GW or /receiving SW		2							2		4		2							1		3
Effect on GWLs, resource, and SW flows, of lowering groundwater level local to site					2		2				4					2		1				3
Effect of discharge of GW on receiving SW flows		2									2		2									2
Significant											0											0
Complex Long-term Monitoring			2								2			2								2
Average Long-term Maintenance		2									2		2									2
Average Long-term Pumping		2									2		2									2
All Energy uses				3							3				3							3
Control systems required for site life plus 30 years	2							2			4	2							2			4
Effects of lowered or backed-up GWLs on biodiversity etc					2						2					2						2
Effects of varied SW flow on biodiversity etc					2		2				4					2		2				4
Effects on biodiversity etc of removing temporary open water bodies in worked-out quarries											0											0
Potential for intrusion of saline/ contamination on (dewatered) GW									2		2									2		2
Effect of barrier to GW flow on GWLs, and potentially on SW flows											0											0
Minor											0											0
Basic or Average long-term monitoring			2								2			2								2
Basic long-term Maintenance											0											0
Basic long-term Pumping											0											0
Control systems required for site life only	2							1			3	2							1			3
Noise, emissions from surface pumps in base of site											0											0
											0											0
Total "Scores"	6	10	4	3	6	0	4	4	4	0	41	6	10	4	3	6	0	3	4	3	1	40

Sustainable Development Indicators: (relevant to sub-water table aspects)	Pumped Underliner Drain (Fig 4.9)	Maintenance	Monitoring	Energy	Derogation of groundwater resource	Increases groundwater levels upgradient	Derogation of surface water resource	Prone to long-term reduction in performance	Potential for contamination by leachate and therefore need to treat large volumes	Inaccessible for repair/replacement	Total "Score"	Barriers (Fig 4.10)	Maintenance	Monitoring	Energy	Derogation of groundwater resource	Increases groundwater levels upgradient	Derogation of surface water resource	Prone to long-term reduction in performance	Potential for contamination by leachate and therefore need to treat large volumes	Inaccessible for repair/replacement	Total "Score"	Surface Water Channel (Fig 4.11)	Maintenance	Monitoring	Energy	Derogation of groundwater resource
Fundamental																											
Complex Long-term Maintenance		1								2	3										1	1					
Complex Long-term Pumping		1									1											0					
Control systems required long-term	2							1			3											0		1			
Potential effect of liner seepage on GW quality											0											0					
Potential effect of liner seepage (anticipated or greater) on quality of intercepted GW or /receiving SW		2							2		4											0					
Effect on GWLs, resource, and SW flows, of lowering groundwater level local to site					2		1				3											0					2
Effect of discharge of GW on receiving SW flows		2									2											0					
Significant											0											0					
Complex Long-term Monitoring			2								2											0					
Average Long-term Maintenance		2									2											0					
Average Long-term Pumping		2									2				2							2					
All Energy uses				3							3				2							2					
Control systems required for site life plus 30 years	2							2			4			BARRIER REQUIRES NO ENERGY BUT LEACHATE REMOVAL ESSENTIAL, AND BARRIER WILL HAVE FINITE SEEPAGE								0					
Effects of lowered or backed-up GWLs on biodiversity etc					2						2						2					2					
Effects of varied SW flow on biodiversity etc					2		2				4											0					2
Effects on biodiversity etc of removing temporary open water bodies in worked-out quarries											0											0					
Potential for intrusion of saline/ contamination on (dewatered) GW									2		2											0					
Effect of barrier to GW flow on GWLs, and potentially on SW flows											0						1					1					
Minor											0											0					
Basic or Average long-term monitoring			2								2			3								3					
Basic long-term Maintenance											0											0		3			
Basic long-term Pumping											0											0					
Control systems required for site life only	2							1			3											0					
Noise, emissions from surface pumps in base of site											0											0					
											0											0					
Total "Scores"	6	10	4	3	6	0	3	4	4	2	42	0	0	3	4	0	3	0	0	0	1	11	0	4	0	0	4

Table 5.7: Engineering Measure: Coincidence of SDIs with Engineering control Measures

Key: 3: Definitely 2: Possibly 1: Possibly but unlikely to be major **Sustainable Development Indicators:** (relevant to sub-water table aspects)	Increases groundwater levels upgradient	Derogation of surface water resource	Prone to long-term reduction in performance	Potential for contamination by leachate and therefore need to treat large volumes	Inaccessible for repair/replacement	Total "Score"	Gravity Cut-Off Drain (Fig 4.12)	Maintenance	Monitoring	Energy	Derogation of groundwater resource	Increases groundwater levels upgradient	Derogation of surface water resource	Prone to long-term reduction in performance	Potential for contamination by leachate and therefore need to treat large volumes	Inaccessible for repair/replacement	Total "Score"	Gravity Underliner Drain (Fig 4.13)	Maintenance	Monitoring	Energy	Derogation of groundwater resource	Increases groundwater levels upgradient	Derogation of surface water resource	Prone to long-term reduction in performance	Potential for contamination by leachate and therefore need to treat large volumes	Inaccessible for repair/replacement	Total "Score"
Fundamental																												
Complex Long-term Maintenance						0										1	1										2	2
Complex Long-term Pumping						0											0											0
Control systems required long-term						1											0											0
Potential effect of liner seepage on GW quality						0									1		1									2		2
Potential effect of liner seepage (anticipated or greater) on quality of intercepted GW or /receiving SW				2		2											0									2		2
Effect on GWLs, resource, and SW flows, of lowering groundwater level local to site						2					2		2				4					2		1				3
Effect of discharge of GW on receiving SW flows		2				2					2						2					2						2
Significant						0											0											0
Complex Long-term Monitoring						0											0											0
Average Long-term Maintenance						0											0											0
Average Long-term Pumping						0		3									3		3									3
All Energy uses						0											0											0
Control systems required for site life plus 30 years						0								2			2								2			2
Effects of lowered or backed-up GWLs on biodiversity etc						0											0											0
Effects of varied SW flow on biodiversity etc						2											0											0
Effects on biodiversity etc of removing temporary open water bodies in worked-out quarries		2				2											0											0
Potential for intrusion of saline/ contamination on (dewatered) GW						0									2		2									2		2
Effect of barrier to GW flow on GWLs, and potentially on SW flows						0											0											0
Minor						0											0											0
Basic or Average long-term monitoring						0			3								3			3								3
Basic long-term Maintenance						3											0											0
Basic long-term Pumping						0											0											0
Control systems required for site life only						0											0											0
Noise, emissions from surface pumps in base of site						0											0											0
						0											0											0
Total "Scores"	0	4	0	2	0	14	0	3	3	0	4	0	2	2	3	1	18	0	3	3	0	4	0	1	2	6	2	21

Table 5.7: SUMMARY OF SUSTAINABILITY "SCORES"

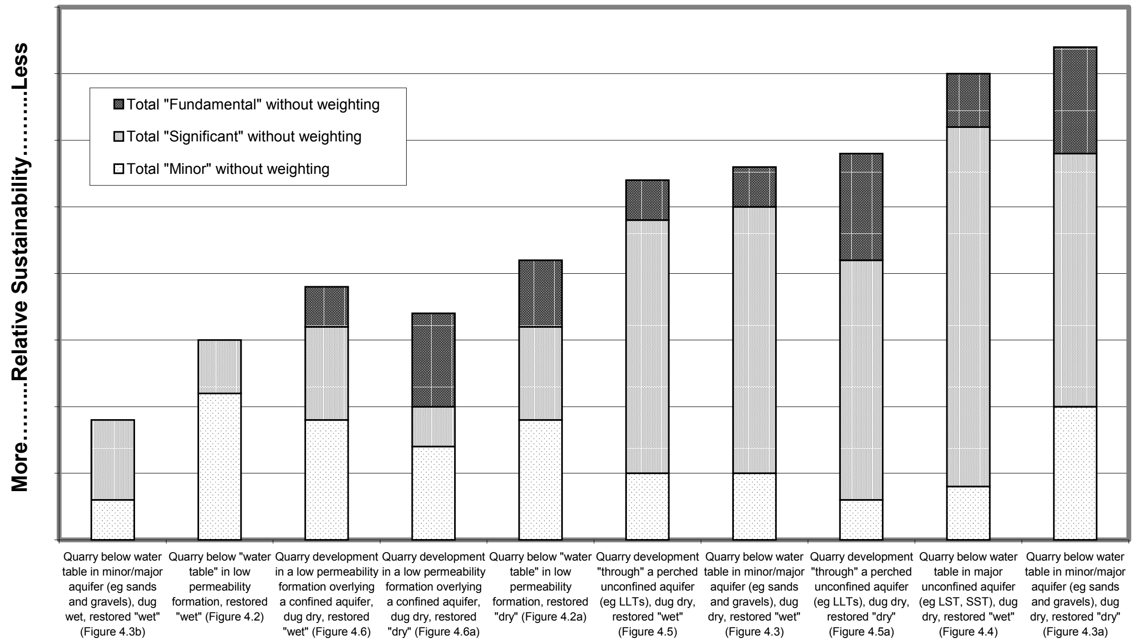
Key:
3: Definitely
2: Possibly
1: Possibly but unlikely to be major

		SITE TYPES ALONE								SITE TYPES PLUS TYPICAL ABOVE WATERTABLE LANDFILL							ENGINEERING MEASURES						
Sustainable Development Indicators: (relevant to sub-watertable aspects)		Landfill in low permeability formation (Fig 4.2)	Landfill in minor/major aquifer with no g/w control (Fig 4.3(i))	Landfill in minor/major aquifer with g/w control (Fig 4.3(ii))	Landfill in Major unconfined aquifer with temporary or no groundwater control (Fig 4.4(i))	Landfill in Major unconfined aquifer with groundwater control (Fig4.4(ii))	Landfill through perched aquifer with possible g/w control (Fig 4.5)	Landfill in low permeability formation overlying confined aquifer with no g/w control (Fig 4.6)	Typical Above-Water Table Landfill	Landfill in low permeability formation (Fig 4.2)	Landfill in minor aquifer with no g/w control (Fig 4.3(i))	Landfill in minor aquifer with g/w control (Fig 4.3(ii))	Landfill in Major unconfined aquifer with temporary or no groundwater control (Fig 4.4(i))	Landfill in Major unconfined aquifer with groundwater control (Fig4.4(ii))	Landfill through perched aquifer with possible g/w control (Fig 4.5)	Landfill in low permeability formation overlying confined aquifer with no g/w control (Fig 4.6)	Wells (Fig 4.7)	Pumped Cut-off Drain (Fig 4.8)	Pumped Underliner Drain (Fig 4.9)	Barriers (Fig 4.10)	Surface Water Channel (Fig 4.11)	Gravity Cut-Off Drain (Fig 4.12)	Gravity Underliner Drain (Fig 4.13)
Fundamental																							
Complex Long-term Maintenance		0	0	0	6	0	0	0	4.5								1	2	3	1	0	1	2
Complex Long-term Pumping		0	0	0	3	0	0	0	0								1	1	1	0	0	0	0
Control systems required long-term		0	0	0	4	2	4	0	3								3	3	3	0	1	0	0
Potential effect of liner seepage on GW quality		1	1	1	2	2	2	1	2								0	0	0	0	0	1	2
Potential effect of liner seepage (anticipated or greater) on quality of intercepted GW or /receiving SW		0	0	2	0	2	2	0	0								4	3	4	0	2	0	2
Effect on GWLs, resource, and SW flows, of lowering groundwater level local to site		0	0	2	3	3	1	0	0								4	3	3	0	2	4	3
Effect of discharge of GW on receiving SW flows		0	0	2	3	3	2	0	0								2	2	2	0	2	2	2
Total "Fundamental" without weighting =		1	1	7	21	12	11	1	9.5	10.5	10.5	16.5	30.5	21.5	20.5	10.5	15	14	16	1	7	8	11
Total "Fundamental" with weighting =	3	3	3	21	63	36	33	3	28.5	31.5	31.5	49.5	91.5	64.5	61.5	31.5	45	42	48	3	21	24	33
Significant																							
Complex Long-term Monitoring		0	0	0	9	0	0	0	0								2	2	2	0	0	0	0
Average Long-term Maintenance		0	0	0	0	6	2	0	4.5								2	2	2	0	0	0	0
Average Long-term Pumping		0	0	2	0	6	2	0	4.5								2	2	2	2	0	3	3
All Energy uses		0	0	8	3	6	2	3	4.5								3	3	3	2	0	0	0
Control systems required for site life plus 30 years		2	2	2	0	0	3	2	0								4	4	4	0	0	2	2
Effects of lowered or backed-up GWLs on biodiversity etc		0	2	2	2	3	1	0	0								2	2	2	2	0	0	0
Effects of varied SW flow on biodiversity etc		0	0	2	0	3	0	0	1								4	4	4	0	2	0	0
Effects on biodiversity etc of removing temporary open water bodies in worked-out quarries		2	2	2	3	2	3	2	0								0	0	0	0	2	0	0
Potential for intrusion of saline/ contamination on (dewatered) GW		0	0	2	0	2	1	0	0								2	2	2	0	0	2	2
Effect of barrier to GW flow on GWLs, and potentially on SW flows		0	2	0	0	0	2	0	0								0	0	0	1	0	0	0
Total "Significant" without weighting =		4	8	20	17	28	16	7	14.5	18.5	22.5	34.5	31.5	42.5	30.5	21.5	21	21	21	7	4	7	7
Total "Significant" with weighting =	2	8	16	40	34	56	32	14	29	37	45	69	63	85	61	43	42	42	42	14	8	14	14
Minor									0														
Basic or Average long-term monitoring		3	3	3	0	3	3	3	0								2	2	2	3	0	3	3
Basic long-term Maintenance		3	3	6	0	0	5	3	0								0	0	0	0	3	0	0
Basic long-term Pumping		3	3	4	0	0	5	3	0								0	0	0	0	0	0	0
Control systems required for site life only		2	0	0	3	0	0	0	0								3	3	3	0	0	0	0
Noise, emissions from surface pumps in base of site		0	0	2	2	2	2	2	2								0	0	0	0	0	0	0
Total "Minor" without weighting =		11	9	15	5	5	15	11	2	13	11	17	7	7	17	13	5	5	5	3	3	3	3
Total "Minor" with weighting =	1	11	9	15	5	5	15	11	2	13	11	17	7	7	17	13	5	5	5	3	3	3	3
Total overall "scores" without weighting		16	18	42	43	45	42	19	26	42	44	68	69	71	68	45	41	40	42	11	14	18	21
Total overall "scores" with weighting	3/2/1	22	28	76	102	97	80	28	59.5	81.5	87.5	135.5	161.5	156.5	139.5	87.5	92	89	95	20	32	41	50
						Combined			Unweighted:	62	69	162	165	173	162	73							

						scores as % more than AWL landfill:																
							Weighted:		37	47	128	171	163	134	47							

Figure 5.1

Site Types without weighting



Site Types with weighting: 3 x Fundamental, 2 x Significant

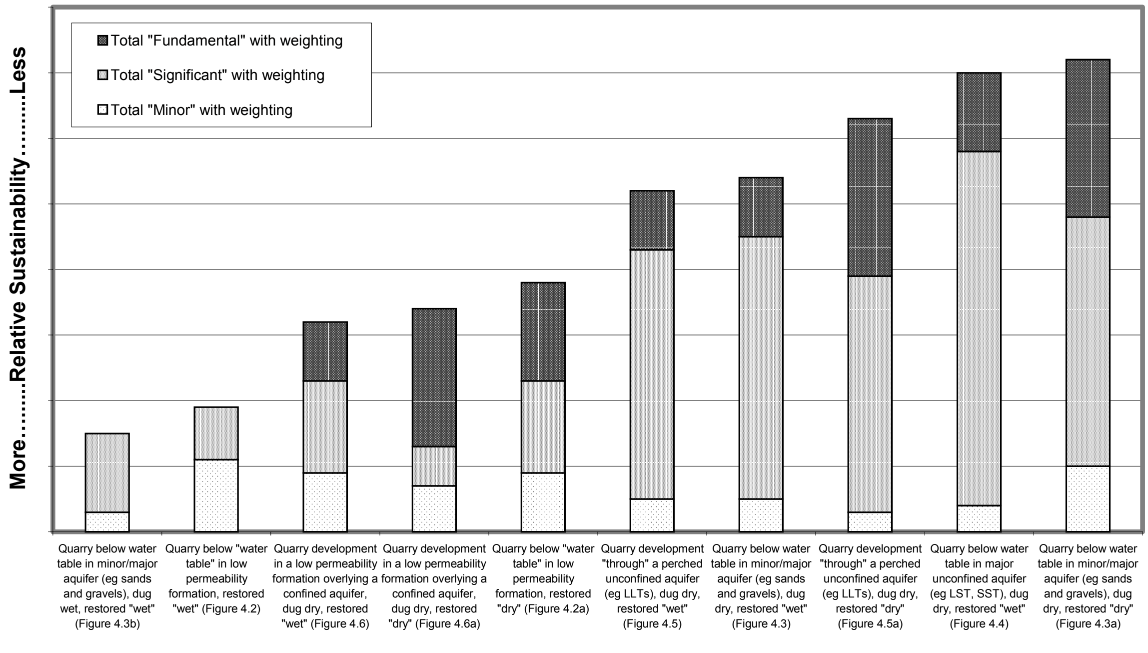
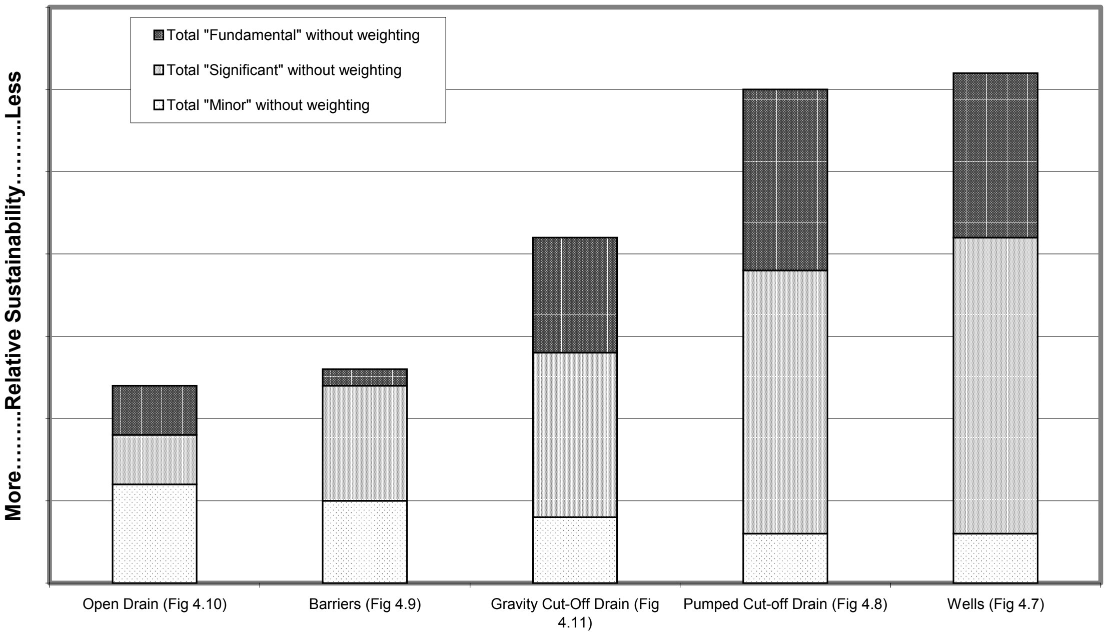


Figure 5.2

Engineering Control Measures without weighting



Engineering Control measures with weighting: 3 x Fundamental, 2 x Significant

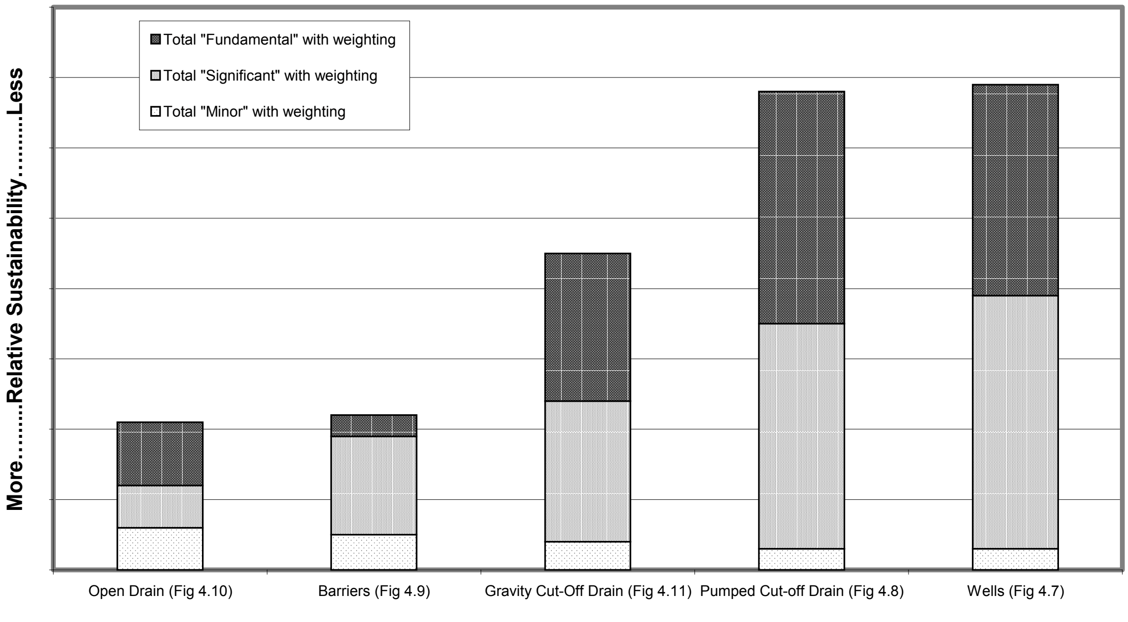


Table 5.8 Relative Sustainability Ranking of Selected Sub-Water Table Landfill Designs

Site Types: Quarry below "water table" in:		**No weighting**	**With weighting**
4.2	low permeability formation, restored "wet"	L/M	L
4.2(a)	low permeability formation, restored "dry"	L/M	M
4.3	minor/major aquifer (e.g. sands and gravels), dug dry, restored "wet"	M	M/H
4.3(a)	minor/major aquifer (e.g. sands and gravels), dug dry, restored "dry"	H	H
4.3(b)	minor/major aquifer (e.g. sands and gravels), dug wet, restored "wet"	L	L
4.4	major unconfined aquifer (e.g. LST, SST), dug dry, restored "wet"	H	H
4.5	"through" a perched unconfined aquifer (e.g. LLTs), dug dry, restored "wet"	M	M/H
4.5(a)	"through" a perched unconfined aquifer (e.g. LLTs), dug dry, restored "dry"	M	H
4.6	low permeability formation overlying confined aquifer, dug dry, restored "wet"	L/M	M
4.6(a)	low permeability formation overlying confined aquifer, dug dry, restored "dry"	L/M	M
Engineering Control Options:			
4.7	Wells	H	H
4.8	Pumped cut-off drain	H	H
4.9	Barriers	L	L
4.10	Surface water channel	L	L
4.11	Gravity cut-off drain	M	M

Key:
LST = limestone
SST = sandstone
LLT = Lower London Tertiary deposits

There are significant planning issues affecting the choice and acceptability of "wet" and "dry" restoration; both can have benefits, e.g. "wet" restoration can provide valuable leisure facilities and wetland habitats, and "dry" restoration can provide productive farmland or development land. Each is extensively used both in the UK and overseas, and the choice must be based on a range of planning, environmental, social and economic factors that contribute to the overall sustainability.

Geology and Hydrogeology

Quarries in *low and relatively low permeability strata* are likely to be more environmentally sustainable than those in high permeability strata, except where a barrier through the high permeability strata is technically feasible.

Quarries in areas of *lower groundwater resource value* (e.g. Non-aquifers) are likely to be more sustainable, but key issues are

- the availability of the groundwater as a resource; and
- the rate of flow.

For example, site types 4.3, 4.4 and 4.5 have the potential to lower local groundwater levels and to draw in contamination from elsewhere (and, by extension, to affect the surface water into which the intercepted groundwater is discharged). These factors are covered by several derived SDIs and the site types are scored accordingly. However, the actual impact will be determined by the sensitivity of the groundwater. The overall acceptability of quarries that require groundwater drainage in aquifers of low to moderate groundwater resource value is dependent on detailed consideration of the significance of the aquifer, flow rate from the drainage system, and, if pumped, the complexity of pumping; recovery time; and impact of failure.

Engineering Controls

Removal of groundwater *up-gradient* of a quarry by *passive means (barrier, gravity cut off or deep surface water drain)* is significantly more sustainable than actively pumped systems as it avoids the need to run and maintain pumps and reduces atmospheric emissions associated with the running of pumps. Gravity drainage depends upon the topography local to the site and may require sloping, valley, or gully sites.

Barriers typically require the least on-going maintenance and energy resources, and are likely to be preferred provided the effects of any backing-up are acceptable. Gravity cut-offs may produce draw-down and therefore greater derogation, and may require more complex maintenance.

Figure 4.5 (a), quarry development “through” a perched unconfined aquifer, indicates a possible further variant on gravity drainage; In some situations, it may be possible (from a practical and environmental perspective) to drain a perched aquifer into lower unsaturated strata, thereby creating an above water table site. Concerns over loss of resources and impacts on baseflow to surface waters and wetlands would, however, need to be fully addressed.

Wells and pumped cut-offs have essentially similar effects, and *are less sustainable* than passive/gravity systems due to their increased potential for derogation of local groundwater resources, their complexity and energy requirement. Pumped cut-offs may use fewer pumps, less energy, and potentially provide a degree of “barrier” effect, but are limited by the constraints of open excavation.

Control, monitoring and management systems should be of *simple or average complexity*; reliance on complex systems in the long term is likely to place an impractical burden on future generations.

Method of Excavation

In some materials such as sand and gravel, the mineral may be extracted “wet”, i.e. by draglines excavating from below the water surface. Such sites are almost invariably also restored “wet”. From the point of view of protecting water resources this is very attractive since there is no need for pumping during or after excavation. Under these operational conditions groundwater resources are unlikely to be derogated unless evaporative losses are particularly large. There may however be planning issues that override these water resource benefits.

5.4 Application of Findings to Strategic Location of Quarries and Selection of Engineering Measures

In order to derive recommendations for strategic policy on the sustainable development of quarries below the water table, it is necessary to set thresholds of acceptability for the sustainable development indicators. Given the inevitable degree of subjectivity, it is suggested that issues be banded into the three areas of:

- preferred characteristic/technique;
- detailed consideration and review required;
- presumption against.

Consideration of the trends identified indicate that, from the perspective of sustainability:

Table 5.9 Preferred Hydrogeologic Environments for Sub-Water Table Quarries

Preferred Characteristic/ Technique:	**Detailed case by case consideration required**	**Presumption against**
Low permeability strata, restored wet Low permeability strata overlying a confined aquifer, restored wet Low permeability strata at accessible depth below high permeability strata, if a barrier is acceptable (for sloping sites) Low groundwater resource value starat (e.g. Non-aquifer) Sites dug wet and restored wet	Low permeability strata, restored dry Low permeability strata overlying confined aquifer, restored dry Moderate permeability / resource value strata (e.g. minor aquifer) (unless gravity drainage is available)	High permeability strata (Availability of gravity drainage may remove presumption, subject to detailed consideration) Minor/major aquifers, restored dry Developments through perched unconfined aquifers
Passive barriers Gravity drainage from up-gradient of site – open channel Minor/basic pumping during operations Simple/average monitoring and controls	Gravity drainage from up-gradient of site – cut-off drains Minor/basic pumping during operations plus < 30 years	Complex or indefinite pumping Complex or indefinite monitoring and control systems

In all considerations, a critical issue is the recoverability/reversibility of negative effects, should maintenance cease or any unexpected incident cause the designed controls to fail. Where this is not possible, then the site/system has a low relative sustainability. Where reversibility **is** possible, its relative ease determines its relative sustainability.

In setting the thresholds it is also necessary to consider:

- the relative weighting of dissimilar SDIs, for example the burden of long-term monitoring compared with threats to biodiversity, or energy use compared with impedance of groundwater levels by barriers; in particular, some SDIs e.g. groundwater and surface water impacts, give multiple and possibly distorting "scores";
- comparison with other societally accepted long-term burdens such as construction of dams or continued development behind flood defences;
- the relative weighting of indicators of specific relevance to the Environment Agency compared with other, more general, issues such as planning controls;
- a risk assessment approach is accepted practice for developments which provide the potential for adverse impact on groundwater quality and resources, by assessing the likelihood and magnitude of possible impacts, and developing (designing and operating) the site to ensure that there are no unacceptable risks, or deciding that such development should not proceed.

6 Conclusions

In addition to its statutory functions, the Environment Agency has responsibilities and a role in relation to sustainable development in the UK. One of the key areas in this regard is the conservation and protection of water resources. The requirement to extract mineral deposits, for a range of purposes, means that there is often conflict of interests between the need to obtain mineral deposits by quarrying and the potential adverse impacts on water resources as a result of quarry development below the water table.

There remains pressure for the approval of quarries that extend below the water table. This report has presented the technical issues associated with sub-water table quarries in a range of hydrogeological settings, in conjunction with the implications for sustainability. A range of sustainability indicators has been refined to produce a key number of most relevance to sub-water table sites.

6.1 Legislative Framework

This report has presented a summary of the key legislation that is relevant to sub-water table quarrying. The primary environmental legislation attached to planning control is the Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999. It falls to local planning authorities in the first instance to consider whether a proposed development requires an environmental impact assessment. Mineral developments that may have significant effect on the water environment also require on environmental impact assessment.

It is at the planning stage that full consideration of environmental effects should be carried out. This should consider the scoping opinions, development, operation and restoration phases for the quarry, so that potential short, medium and long-term effects are assessed at an early stage.

The Environment Agency, as a statutory consultee in applications for quarry developments, will have regard to its duties under the Water Resources Act 1991 and Environment Act 1995 to conserve and protect water resources and preserve, and where appropriate, enhance conservation of the water environment. Involvement with developers at an early a stage as possible is preferred, in order that all water-related issues can be identified and addressed in the best means possible in the development proposals.

New legislation is proposed that will allow regulation of de-watering activities. All abstractions above a specified threshold quantity will require authorisation, regardless of the purpose for which the water is abstracted. This will enable the Environment Agency to manage and protect groundwater resources more effectively than under the current system of exemption from abstraction licensing for quarry de-watering.

6.2 Current Sub-Water Table Quarrying

Information has been reviewed in this report to give an overview of sub-water table quarry development in England and Wales. This was obtained from published information, including from the DETR 1998 publication “Reducing the Effects of Surface Mineral Workings on the Water Environment – A Guide to Good Practice” which provides a comprehensive review of surface mineral working in the UK, and from information provided by Environment Agency area offices in response to a questionnaire prepared as part of this study.

A summary of the hydrogeological characteristics of the main rock types in mineral workings is presented, together with the most common measures used for water management. The most significant impacts of quarrying below the water table are identified as those associated with de-watering. These and common methods used in mitigation are presented. It is concluded that the majority of impacts are generally of greatest significance in sandstone, limestone and chalk aquifers, i.e. major aquifers, where the volumes of groundwater to be managed are largest, and the groundwater resources are most valuable.

Responses to a questionnaire sent to Environment Agency staff confirmed that examples of sub-water table sites that were of concern to them were primarily in major aquifer locations. While the information obtained from this survey was limited, it did indicate that:

- approximately half of operational quarries extend below the water table;
- about a third of sub-water table sites are located on major aquifers, although this figure is probably influenced by the large number in sands and gravels in the Thames Region;
- pumping to a watercourse is the most common method of water management during the operational phase of quarries;
- qualitative risk assessments are generally carried out for quarries on major and minor aquifers – quantitative assessments are less common and restricted to a proportion of major and minor aquifer sites.

6.3 Hydraulic Regimes

A range of hydraulic regimes associated with sub-water table quarrying has been presented, taking into account a range of hydrogeological environments. Potential benefits and problems associated with each, in terms of water resources, have been identified. Engineering options for groundwater control are also described, identifying those that are feasible, potentially feasible or unsuitable in relation to hydrogeological and engineering circumstance.

This chapter of the report provides the link between consideration of technical issues that are associated with mineral extraction below the water table and factors that relate to the sustainability of such developments from the water resources perspective. Schematic diagrams have been used which present the key potential and time-related factors for sustainability associated with the hydrogeological regimes considered. These have been used to develop a number of sustainability indicators specific to the project.

6.4 Sustainability Indicators

Chapter 5 describes a process for deriving indicators of the relative sustainability of sub-water table quarry designs. Sustainable development indicators are normally selected for the purpose of monitoring over time, to establish their rate of change and thereby enable trends to be observed and priorities for change to be identified. In this instance, indicators were first selected from the Government's full list, developed into appropriate indicators and then considered against a range of natural and engineering settings to establish the relative importance of defining factors.

The factors described below have been derived from this process as those most appropriate for translation into strategic guidelines, to encourage development in those areas with the most favourable attributes, using the most sustainable engineering approaches.

From the perspective of sustainability the characteristics of site hydrogeology, restoration type, and engineering control options may be broadly grouped into the three bands of "preferred characteristic/technique"; "detailed consideration and review required"; and "presumption against", i.e.:

Table 6.1 Preferred Hydrogeologic Environments for Sub-Water Table Quarries

Preferred Characteristic/ Technique:	**Detailed case by case consideration required**	**Presumption against**
Low permeability strata, restored wet Low permeability strata overlying a confined aquifer, restored wet Low permeability strata at accessible depth below high permeability strata, if a barrier is acceptable (for sloping sites) Low groundwater resource value starat (e.g. Non-aquifer) Sites dug wet and restored wet	Low permeability strata, restored dry Low permeability strata overlying confined aquifer, restored dry Moderate permeability / resource value strata (e.g. minor aquifer) (unless gravity drainage is available)	High permeability strata (Availability of gravity drainage may remove presumption, subject to detailed consideration) Minor/major aquifers, restored dry Developments through perched unconfined aquifers
Passive barriers Gravity drainage from up-gradient of site – open channel Minor/basic pumping during operations Simple/average monitoring and controls	Gravity drainage from up-gradient of site – cut-off drains Minor/basic pumping during operations plus < 30 years	Complex or indefinite pumping Complex or indefinite monitoring and control systems

The recoverability/reversibility of significant negative effects due to failure of control systems or maintenance, or any unexpected incident, must be considered in all cases. If negative effects are not reversible, then the site/system has a low relative sustainability, and depending on the site-specific considerations, the precautionary principle may be invoked.

In setting the thresholds it is also necessary to consider:

- the relative weighting of dissimilar SDIs;
- comparison with other societally accepted long-term burdens;
- the relative weighting of indicators of specific relevance to the Environment Agency compared with other, more general, issues;

- the risks to groundwater in comparison with accepted practice for above water table sites, in terms of acceptance of a finite risk, scale of potential problem, ability to remediate, ease of so doing and the time available.

It is recommended that this framework should be reviewed by the Environment Agency periodically and evaluated against field data, both strategic and site-specific. This review should also consider the potential advantages and disadvantages of "starring" certain attributes, such that a given number of "starred" issues would trigger a result of "unacceptable".

Postscript

This review has considered only water-related issues of sub-water table quarrying within the wider scope of assessing whole activity sustainability . In that few, if any, aspects of life are truly sustainable, other factors should also be taken into account in determining the acceptability or otherwise of sub-water table quarrying. These include:

- costs;
- use of resources;
- other options for obtaining minerals, e.g.:
  - lateral extensions with greater land take;
  - production of secondary aggregates from recycled materials;
- planning issues;
- safety; and
- relative impacts of alternative locations.

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KEY WORDS

Aeration zone	That zone below the surface of the ground but above the saturation zone, and in which water is present at below atmospheric pressure and where air/gases are present at atmospheric pressure *(used in the definition of water table)*
Aftercare	The steps necessary to bring the land to the required standard for the planned afteruse [after MPG7] The period prior to the granting of a certificate of completion during which maintenance and monitoring work is needed to ensure that the restored quarry does not cause pollution of the environment, harm to human health or adverse effects on local amenities
Anisotropic	Having different physical properties in different directions
Aquifer	A permeable geological stratum or formation that is capable of both storing and transmitting water in significant amounts. A *confined aquifer* is where upper and lower layers are low permeability which confine the groundwater under greater than atmospheric pressure. An *unconfined aquifer* is where the upper surface of a saturated zone forms a water table within the water-bearing stratum
Aquifer thickness	The thickness of the saturated zone
Attenuation	A decrease in concentration caused by any of a variety of mechanisms, individually or in combination, including dilution, adsorption, precipitation, ion-exchange, biodegradation, oxidation, reduction.
Authorisation	Regulation 1(3) (Groundwater Regulations). An authorisation under Regulation 18 (disposal or tipping) or 19 (a conditional notice for control of other activities) of the Groundwater Regulations 1998, a discharge consent under section 85 of the Water Resources Act 1991 or Part II Control of Pollution Act 1974 (Scotland), an authorisation under Part I of the Environmental Protection Act 1990 (IPC authorisation), or an authorisation under the Pollution Prevention & Control Regulations 2000 (PPC authorisation).
Controlled waters	Defined by Water Resources Act 1991, Part III, Section 104. All rivers, canals, lakes, ground waters, estuaries and coastal waters to three nautical miles from the shore
Darcy's Law	Empirical law that describes groundwater movement at a macroscopic scale
Direct discharge	Regulation 1(3) of the Groundwater Regulations 1998 – the introduction into groundwater of any substance in List I or II without percolation through the ground or subsoil
Environmental impact	The total effect of any operation on the environment

Groundwater	(Regulation 1(3) of the Groundwater Regulations 1998.) All water that is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil
Ground waters	(s104, WRA, 1991) – any waters contained in underground strata
Guidelines	Non-enforceable government statements of suitable approaches for achieving specified aims
Homogeneous	Uniform, consisting of parts all of the same kind
Hydraulic conductivity	A coefficient of proportionality describing the rate at which water can move through a permeable medium. The density and kinematic viscosity of the water must be considered in determining hydraulic conductivity
Hydraulic head	The sum of the elevation head, the pressure head, and the velocity head at a given point in the aquifer
Inert materials	Materials that will not physically or chemically react or undergo biodegradation
Indirect discharge	Regulation 1(3) of the Groundwater Regulations 1998 – the introduction into groundwater of any substance in List I of II after percolation through the ground or subsoil.
Isotropic	The condition in which hydraulic properties of the aquifer are equal in all directions
List I and List II substances	*Schedule to the Groundwater Regulations 1998*. Repeated from the Groundwater Directive and **not** necessarily the same as the List I and II substances noted in the Dangerous Substances Directive.
Mixing zone	The region in which two substances, such as contaminants mix and concentrations are diluted.
Perched water	An accumulation of liquid at a level above that of the adjacent water table. Often caused by zones of low permeability strata (or wastes) which inhibit downward percolation
Porosity	The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment
Prior Investigation	Regulation 7 of the Groundwater Regulations 1998. An examination undertaken prior to authorisation to determine the hydrogeological conditions of the area covered, the possible purifying powers of the soil and subsoil, the risk of pollution and the potential alteration of the quality of the groundwater from the discharge, the eventual aim being to establish whether the discharge of substances into groundwater is a satisfactory solution from the point of view of the environment (that is, it does not make the groundwater unsuitable with respect to present or potential future uses). Prior investigation is intended to help identify any necessary technical precautions to prevent pollution from potential discharges/disposals

Receptor	An entity, such as a human, animal, controlled waters, plant, building or the atmosphere, which is vulnerable to the adverse effects of a hazardous substance or agent
Requisite surveillance of groundwater	That investigation in the form of monitoring which is considered necessary by the Environment Agency to determine whether the given activity affects the quantity and quality of the groundwater, and/or to ensure that the necessary precautions have been taken to prevent groundwater pollution..
Saturated zone	The zone in which the voids of the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer
Site investigation	Assessment of the condition of a site, including past and ongoing procedures and subsurface conditions
Unsaturated zone	The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched groundwater may exist in the unsaturated zone. Also called zone of aeration and vadose zone
Water resources	Waters that are potentially extractable for industrial, private or public use
Water table	The planar surface between the saturation and aeration zones, on which water is at exactly atmospheric pressure. For the purposes of assessing whether a discharge is direct or indirect, a representative winter water table level should be employed, based on hydrogeological records and/or expert opinion

APPENDICES

APPENDIX 1
Planning Policy Guidance Notes
Minerals Planning Policy Guidance Notes

Planning Policy Guidance Notes		
	Title	
PPG1	General considerations and the Development Plan System	PPG1 was first published in 1988 as an introduction to the new series of Planning Guidance Notes. It provided an overview and general statement of the objectives of the planning system. The second edition first presented the significance of sustainable development as the basis for planning policy and the 1997 edition placed more emphasis on the general principles of sustainable development, to which there are now 15 indicators. Amongst these are waste, minerals extraction and conservation of water. The PPG adopts the Brundtland definition of sustainability as ”development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.
PPG10	Planning and Waste Management	PPG 10, published in September 1999, replaced the parts of PPG23 (discussed below) which specifically dealt with waste management issues. The remainder of PPG 23 is due for review in the near future but, meanwhile, remains valid. PPG10 contains notes under Planning Considerations, particularly section g deals with protection of surface and underground water, with PPG23 and WMP26B continuing to contain relevant advice. PPG10 introduces the government’s intention to set out a policy framework for sustainable waste management and follows publication of the 1995 White Paper Making Waste Work: A Strategy for Sustainable Waste Management. The guidance note provides advice about how the land-use planning system should contribute to sustainable waste management through the provision of the required waste management facilities in England and explains how this provision is regulated under the statutory planning and waste management systems. The guidance sets out the general policy context and the criteria for siting facilities, and is intended to benefit all other interested parties, including the Environment Agency. Four principles for sustainable waste management are introduced: Best Practicable Environmental Option; Regional Self-Sufficiency; Proximity Principle; Waste Hierarchy. These principles are based on the BPEO defined as *“the outcome of a systematic consultative and decision making*

Planning Policy Guidance Notes		
	Title	
		procedure which emphasises the protection and conservation of the environment across land, air and water". The BPEO procedure establishes for a given set of objectives, the option that provides the most benefits or the least damage to the environment, as a whole, at acceptable cost, in the long term as well as in the short term. The PPG notes that Waste Planning Authorities need to develop waste planning strategies for their area, which take account of legislation, waste management strategy, national and regional planning guidance on waste, and the strategies of the Regional Technical Advisory Bodies (RTABs). The PPG summarises the above legislation and guidance. Specifically it references the Environment Agency aims to prevent or minimise the effects of pollution on the environment. Although the decision on land-use planning matters are the responsibility of WPAs they should take the Agency's advice into account when developing their policies and making decisions. Clearly the PPG references the information being gathered by the Agency and their communication with the RTABs. The PPG provides guidance on Development plans and a chapter on Development control. The annexes reference planning considerations and criteria for selection of sites including *protection of surface and underground water (A11.g)*. Paragraphs A34 to A36 reference the use of PPG23 (where not superseded by PPG10) and Waste Management Paper 26B. With respect to landfill and landraising, PPG10 states that "a planning condition will be required to control drainage and disposal of surface water and to prevent pollution of groundwater by leachate." The PPG references the expectation "*for surroundings to be investigated carefully by suitable experts to determine the geological conditions and the behaviour of surface water and groundwater*." In addition the PPG references that the Agency will provide advice on flooding and the potential effects of the development on the behaviour of floodwater and the potential generation of additional surface water run-off.
PPG12	Development Plans and Regional Planning Guidance	PPG12 covers the preparation of regional guidance and development plans of various types. Development Plans are the main guide to planning decision by local authorities and others. Their status is emphasised by the Planning and Compensation Act 1991 which requires planning decisions to accord with the development plan unless material considerations indicate otherwise. Chapter 5 of PPG12 includes "other environmental considerations in plans". The PPG acknowledges that

Planning Policy Guidance Notes		
	Title	
		Development Plans may include policies for control of pollution, coastal protection, flood defence and land drainage issues, which may influence the location of new development, and the need to protect water quality. Paragraph 6.19 states "Particular attention should be paid to the protection of groundwater resources which are susceptible to a wide range of threats arising from land-use policies". The PPG recognises that account should be taken of groundwater vulnerability mapping. It also recognises that Development Plans should take account of the proximity of existing or proposed mineral extraction, their environmental effects, in order to minimise the impact of such workings on new development and to avoid unnecessary constraints on essential minerals operations. PPG 12 references circular 25/85 Minerals Workings – Legal aspects relating to Restoration of Sites with High Water Tables.
PPG14	Development on Unstable Land: Landslides and Planning	PPG14 sets out the broad planning and technical issues in respect of development on unstable land. The PPG acknowledges that the range of activities which may contribute to slope instability includes:- "the disposal of wastes" and "mineral extraction beneath slopes". Slope stability reports must include reference to ground conditions including seepage lines and wet areas which might indicate groundwater emergence.
PPG23	Planning and Pollution Control	PPG23 references the fact that in considering applications for landfill or landraising development, planning authorities should take into account the effect of the waste disposal activity on the environment, the proposals for the restoration of the land, and its intended after-use. This includes the geology and hydrogeology of the site. Annex 3 of the PPG on Water Quality, deals with implementation of the Water Act 1989 (The 1989 Act) and section 85 of the Water Resources Act 1991(the 1991 Act). The 1989 Act gave the National Rivers Authority (now the Environment Agency) statutory responsibility for conservation and enhancement of water resources, for licensing water abstraction, and for the control of water quality and of pollution in relation to "controlled waters". The annex explains Section 85 of the Water Resources Act 1991, which creates a number of offences relating to discharging or otherwise causing or permitting the entry of polluting matter or effluent into controlled or other waters. The annex explains the requirements for the NRA, now the Environment Agency, as an important

Planning Policy Guidance Notes		
	Title	
		consultative role in the town and country planning system. The supply of water and sewage disposal are capable of being material considerations in planning applications and appeals, and should also be taken into account in drawing up development plans. Annex 4 of the PPG on Waste Management covers Part II of the Environmental Protection Act 1990 which deals with responsibility for waste regulation functions to waste regulation authorities. Annex 11 of the PPG deals with Restoration Aftercare and After-use of landfill sites for agricultural, amenity or forestry use. The Planning and Compensation Act 1991 gives powers to local planning authorities to impose aftercare conditions on planning permissions, revocation orders and discontinuance orders in respect of development involving the depositing of any types of refuse or waste materials, and therefore applies to landfill sites. Advice on the imposition of aftercare conditions in respect of mineral workings is given in Minerals Planning Guidance Note 7 (MPG7) The Reclamation of Mineral Workings, and may to some extent be helpful for the reclamation of landfill sites. It advises that planning conditions for the reclamation of a proposed landfill site should be drawn up with a particular after-use in mind. PPG23 is due to be revised in the near future.

Minerals Planning Policy Guidance Notes		
Reference	**Title**	**Notes**
MPG 1	General Considerations and the Development Plan System	MPG1 provides an overview of the policies and operation of the planning system in relation to minerals. This references the "need to protect flow and quality of surface and groundwater and the need to ensure that mineral extraction does not cause unacceptable changes to the water environment, particularly water resources". "The potential of certain mineral development to affect aquifers and groundwater, individually or cumulatively, may therefore need to be considered on developing areas of mineral development in mineral local plans, as well as being material considerations in determining planning applications for individual sites". Paragraph 35 notes that the key objectives of sustainable development in relation to minerals planning are (inter alia): "(ii) to ensure that the environmental impacts caused by mineral operation and the transport of minerals are kept as far as possible, to an acceptable minimum"; and "(iv) to encourage sensitive working, restoration and aftercare practices so as to preserve or enhance the overall quality of the environment".
MPG2	Applications, Permissions and Conditions	MPG2 contains detailed advice on setting planning permission conditions in respect of the limitation on water supply, land drainage, river pollution, limitation on depth of working, disposal of wastes, protection of groundwater, surface water, drainage and pollution control. MPG2 references guidance on current good practice for land filling controlled wastes and the relationship between planning and waste disposal legislation. The protection of groundwater through the EEC directives is referenced, as is the Water Resources Act 1991. The effect of mineral development upon water supply, pollution and land drainage and the legislation concerned with this is all referenced together with the requirement to consult with the Environment Agency. There is special reference to mineral workings below the level of the water table.

Minerals Planning Policy Guidance Notes		
Reference	**Title**	**Notes**
MPG6	Guidelines for Aggregates Provision in England	MPG6 makes specific reference to the concept of sustainability in relation to the supply of aggregates, efficient use of aggregates and use of alternative sources of secondary and recycled materials. It notes the need to encourage sensitive working practices. Paragraph 97 references Water interests and refers back to the MPG7 and DoE Circular 25/85.
MPG7	The Reclamation of Mineral Workings	MPG7 provides detailed advice on reclamation i.e. restoration and after-use of mineral workings. This includes restoration of areas with a high water table.
MPG9	Planning and Compensation Act 1991: Interim Development Order Permissions (IDOs) – Conditions	The protection of groundwater is referenced in Annex A of MPG9 "Illustrative Guide to Conditions" which provides examples of appropriate planning conditions.
MPG11	The Control of Noise at Surface Mineral Workings	MPG11 advises mineral planning authorities and the industry on how the environmental performance of the industry can be improved by the control of noise from operations. The guidelines provide advice on how both planning controls and good environmental practice can be used to keep noise emissions to environmentally acceptable limits.

Minerals Planning Policy Guidance Notes		
Reference	**Title**	**Notes**
MPG14	Environment Act 1995: Review of Mineral Planning Permissions	MPG14 introduces the requirement for mineral planning authorities to undertake periodic reassessments of existing mineral permissions and to make changes where appropriate to the conditions which are imposed.

APPENDIX 2
Sustainable Development Indicators

Sustainable Development Indicators May 1999

1 Amount of secondary/recycled aggregates used compared with virgin aggregates (to be developed)
2 Land covered by restoration and aftercare conditions
3 Biodiversity action plans
4 Native species at risk
5 Trends in plant diversity
6 Countryside quality (to be developed)
7 Area of woodland in the UK
8 Ancient semi-natural woodland
9 Sustainable management of woodland (to be developed)
10 Net loss of greenfield soils to development
11 Concentrations of organic matter in agricultural topsoils
12 Populations of wild birds (headline)
13 Landscape features - hedgerows, stonewalls and ponds
14 Extent and management of SSSIs
15 Nutrients in water
16 Coastal and estuarine water quality
17 Inputs of contaminants into the sea
18 Compliance with Bathing Water Directive
19 Biodiversity in coastal/marine areas (to be developed)
20 Water demand and availability
21 Water affordability
22 Water leakage
23 Abstractions by purpose
24 Low flow in rivers (to be developed)
25 Acidification in the UK
26 Carbon dioxide emissions by end user
27 Depletion of fossil fuels
28 Electricity from renewable sources
29 Concentrations of persistent organic pollutants (to be developed)
30 Dangerous substances in water
31 Emissions of greenhouse gases (headline)
32 Rise in global temperature
33 Waste arisings and management (headline)
34 UK resource use (to be developed)
35 Waste by sector (to be developed)

36 Household waste and recycling
37 Materials recycling
38 Energy efficiency of economy
39 Energy use per household
40 Hazardous waste
41 Prices of key resources (e.g. fuel, water)
42 Real changes in the cost of transport
43 Enforcement of regulations (to be developed)
44 Public understanding and awareness
45 Expenditure on pollution abatement
46 Total output of the economy (GDP)
47 Emissions of greenhouse gases
48 Days when air pollution is moderate or high
49 Road traffic
50 Rivers of good or fair quality
51 Populations of wild birds
52 Green housekeeping in Government
53 Women in public appointments and in senior positions
54 Individual action for sustainable development
55 Awareness in schools (to be developed)
56 Investment in public, business and private assets
57 Proportion of people of working age who are in work
58 Qualifications at age 19
59 Expected years of healthy life
60 Homes judged unfit to live in
61 Level of crime
62 New homes built on previously developed land
63 Satisfaction with quality of life (to be developed)
64 Index of Local Deprivation
65 Regional variations in GDP
66 Indicators of success in tackling poverty and social exclusion (to be developed)
67 New business start ups and failures
68 Ethnic minority unemployment
69 Sea level rise
70 Discharges from the nuclear industry
71 Radioactive waste stocks
72 Days when air pollution is moderate or high (headline)

73 Concentrations and emissions of selected air pollutants
74 Sulphur dioxide and nitrogen oxides emissions
75 Ozone depletion
76 Rivers of good or fair quality (headline)
77 Fish stocks around the UK fished within safe limits
78 State of the world's fisheries
79 Access to the countryside (to be developed)
80 Number of countries with national forest programmes
81 Global population
82 Global poverty
83 Overseas development aid/bilateral aid to low income countries
84 UK public expenditure on global environmental protection
85 Implementation of multilateral environmental agreements
86 International emissions of carbon dioxide per capita
87 World and UK materials consumption levels per capita (to be developed)

Proposed headline indicators of sustainable development	**December 1999**
Maintenance of high and stable levels of economic growth and employment	*So that everyone can share in high living standards and greater job opportunities, and to generate the income and wealth needed to pay for essential infrastructure and future investment.*
Economic growth	*Total output of the economy (gross domestic product)*
Social investment	*Investment in public assets (transport, hospitals, schools, etc)*
Employment	*People of working age who are in work*
Social progress which recognises the needs of everyone	*Ensuring that better health, a good education and decent housing, are available to everyone in our society, no matter who they are and where they live*
Health	*Expected years of healthy life*
Education and training	*Qualifications at age 19*
Housing quality	*Homes judged unfit to live in*
Effective protection of the environment	*Limiting the emissions of greenhouse gases which are causing the global climate to change, ensuring that people's health does not suffer from poor air quality or other pollution, and protecting wildlife and the countryside*
Climate change	*Emissions of greenhouse gases*
Air pollution	*Days of air pollution*
Transport	*Road traffic*
Water quality	*Rivers of good or fair quality*
Wildlife	*Populations of wild birds*
Land use	*New homes built on previously developed land*
Prudent use of natural resources	*Ensuring that we use resources efficiently and minimise waste*
Waste	*Waste and waste disposal*

From *Sustainability Counts*, DETR 1999

Headline Indicators from the Sustainable Development Strategy – December 1999

H - Headline indicators	
Maintaining high and stable levels of economic growth and employment	
H1	Total output of the economy (GDP and GDP per head)
H2	Total and social investment as a percentage of GDP
H3	Proportion of people of working age who are in work
Social progress which recognises the needs of everyone	
H4	Indicators of success in tackling poverty and social exclusion
H5	Qualifications at age 19
H6	Expected years of healthy life
H7	Homes judged unfit to live in
H8	Level of crime
Effective protection of the environment	
H9	Emissions of greenhouse gases
H10	Days when air pollution is moderate or high
H11	Road traffic
H12	Rivers of good or fair quality
H13	Populations of wild birds
H14	New homes built on previously developed land
Prudent use of natural resources	
H15	Waste arisings and management
A - Sustainable economy	
Doing more or less: improving resource efficiency	
A1	UK resource use D
A2	Energy efficiency of economy
A3	Energy use per household
A4	Waste by sector D
A5	Household waste and recycling
A6	Materials recycling
A7	Hazardous waste
B - Economic stability and competitiveness	
B1	Rate of inflation
B2	Public sector net borrowing and net debt
B3	Labour productivity
B4	UK imports, exports, trade balance
B5	Social investment as a per cent of GDP

C – Developing skills and rewarding works	
C1	16 year olds with no qualifications
C2	Adult literacy/numeracy
C3	Learning participation
C4	Businesses recognised as Investors In People
C5	Proportion of people of working age in workless households
C6	Proportion of people of working age out of work for more than two years
C7	Proportion of lone parents, long-term ill and disabled people who are economically active
C8	People in employment working long hours
C9	Low pay D
C10	Work fatalities and injury rates; working days lost through illness
C11	UK companies implementing ethical trading codes of conduct D
D – Sustainable production and consumption	
D1	Consumer information D
D2	Consumer expenditure
D3	Energy and water consumption by sector/Waste and hazardous emissions by sector D
D4	Adoption of environmental management systems (ISO14001) and EMAS
D5	Corporate environmental engagement
D6	Environmental reporting D
D7	Household water use and peak demand
D8	Thermal efficiency of housing stock
D9	Primary aggregates per unit of construction value
D10	Construction and demolition waste going to landfill
D11	Energy efficiency of new appliances
D12	Pesticide residues in food
D13	Area under agreement under the Environmentally Sensitive Area & Countryside Stewardship agri-environment schemes
D14	Area converted to organic production
D15	Energy efficiency of road passenger travel/Average fuel consumption of new cars
D16	Sustainable tourism D
D17	Leisure trips by mode of transport
D18	Overseas travel
D19	Chemical releases to the environment D
D20	Freight transport by mode
D21	Heavy goods vehicle mileage intensity

BUILDING SUSTAINABLE COMMUNITIES	
E - Promoting economic vitality and employment	
E1	Regional variations in GDP
E2	Index of local deprivation
E3	Truancies and exclusions from school/teenage pregnancies
E4	New business start-ups net of closures
E5	Ethnic minority employment and unemployment
F - Better health for all	
F1	Death rates from cancer, circulatory disease, accidents and suicides
F2	Respiratory illness
F3	Health inequalities
F4	NHS hospital waiting lists
G - Travel	
G1	Passenger travel by mode
G2	How children get to school
G3	Average journey length by purpose
G4	Traffic congestion
G5	Distance travelled relative to income
J - Access	
J1	People finding access difficult
J2	Access to services in rural areas
J3	Access for disabled people
J4	Participation in sport and cultural activities
J5	Temporary accommodation/rough sleepers
J6	Fuel poverty
K - Shaping our surroundings	
K1	Vacant land and properties and derelict land
K2	New retail floor space in town centres and out of town
K3	Population growth
K4	Household growth
K5	Buildings of Grade I and II* at risk of decay
K6	Quality of surroundings
K7	Access to local green space D
K8	Noise levels
K9	Fear of crime

L – Involvement and stronger institutions	
L1	Number of local authorities with LA21 strategies
L2	Voluntary activity
L3	Community spirit
MANAGING THE ENVIRONMENT AND RESOURCES	
M – An integrated approach	
M1	Concentrations of persistent organic pollutants
M2	Dangerous substances in water
M3	Radioactive waste stocks
M4	Discharges from the nuclear industry
N – Climate change and energy supply	
N1	Rise in global temperature
N2	Sea level rise
N3	Carbon dioxide emissions by end user
N4	Electricity from renewable sources
N5	Depletion of fossil fuels
P – Air and atmosphere	
P1	Concentrations of selected air pollutants
P2	Emissions of selected air pollutants
P3	Sulphur dioxide and nitrogen oxides emissions
P4	Acidification in the UK
P5	Ozone depletion
Q – Freshwater	
Q1	Nutrients in water
Q2	Water demand and availability
Q3	Water affordability
Q4	Water leakage
Q5	Abstractions by purpose
Q6	Sites affected by water abstraction D
R – Seas oceans and coasts	
R1	Estuarine water quality, marine inputs
R2	Compliance with Bathing Water Directive
R3	Biodiversity in coastal/marine areas D
R4	Fish stocks around the UK fished within safe limits
R5	State of the world's fisheries

S - Landscape and wildlife	
S1	Net loss of soils to development
S2	Concentrations of organic matter in agricultural topsoils
S3	Trends in plant diversity
S4	Biodiversity action plans
S5	Landscape features - hedges, stone walls, ponds
S6	Extent and management of SSSIs
S7	Countryside quality D
S8	Access to the countryside D
S9	Native species at risk
S10	Area of woodland in the UK
S11	Area of ancient semi-natural woodland in GB
S12	Sustainable management of woodland D
S13	Number of countries with national forest programmes
S14	Amount of secondary/recycled aggregates used compared with virgin aggregates D
S15	Land covered by restoration and aftercare conditions
SENDING THE RIGHT SIGNALS	
T - Sending the right signals	
T1	Greening government operations
T2	Women in public appointments and senior positions
T3	Prices of key resources - fuel
T4	Real changes in the cost of transport
T5	Expenditure on pollution abatement
T6	Enforcement of regulations
T7	Public understanding and awareness
T8	Awareness in schools
T9	Individual action for sustainable development
INTERNATIONAL CO-OPERATION AND DEVELOPMENT	
U - International co-operation and development	
U1	Global poverty
U2	Net Official Development Assistance (ODA)
U3	Global population
U4	UK public expenditure on global environment protection
U5	Implementation of multilateral environmental agreements D
U6	International emissions of carbon dioxide per head
U7	World and UK materials consumption levels per head

D: under development