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Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes

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This original document is part of a suite of documents published by the National Roads Authority (NRA) in the 2000s and early 2010s as part of its 'Four Stage Strategy – The Environmental Integration Model'. These documents were the NRA's *Environmental Assessment and Construction Guidelines* and *Guidelines for the Creation, Implementation and Maintenance of an Environmental Operating Plan*.

For further explanation on the 'Four Stage Strategy – The Environmental Integration Model,' refer to *TII Environmental Strategy Section 4: Delivery Framework.*

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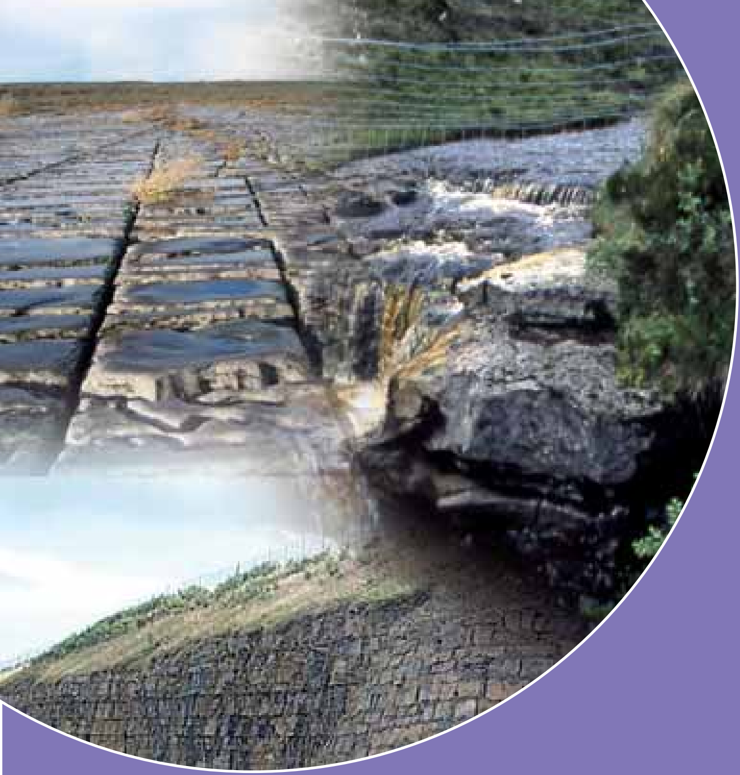

National Roads Authority

Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes

NRA
National Roads Authority
An tÚdarás um Bóithre Náisiúnta

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Disclaimer

CONTENTS

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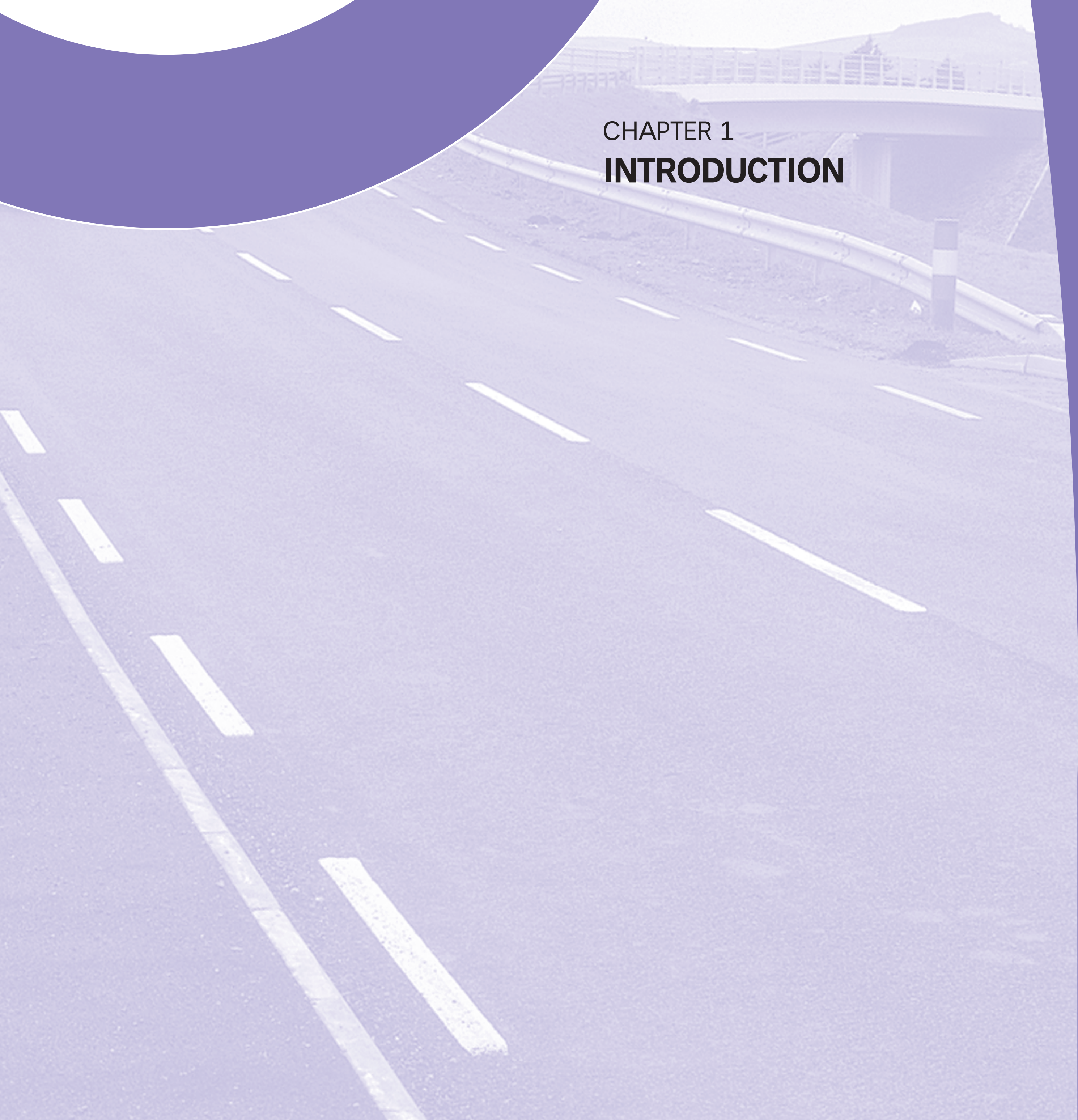
An tÚdarás um Bóithre Náisiúnta

CHAPTER 1

INTRODUCTION



1 INTRODUCTION

1.1 Background and Legislative Context

National road schemes are major infrastructure developments and as such, can give rise to potentially significant impacts on the existing environment (be it human, natural, physical, social or economic). One of the key objectives in planning and designing road schemes is to ensure that likely significant impacts are identified at an early stage and are either avoided entirely or minimized insofar as it is possible to do so. This is achieved in part by the Environmental Impact Assessment (EIA) process which, for national road schemes, is implemented following procedures set out in the National Roads Authority's (NRA) *National Roads Project Management Guidelines* ('NRPMG').

The aim of this document is to provide guidance on the assessment of geological, hydrological and hydrogeological impacts during the planning and design of national road schemes in Ireland. It expands on references to soil and water contained in the NRPMG and specifically outlines the approach to be adopted in the consideration and treatment of geology, hydrology and hydrogeology at the Constraints Study, Route Corridor Selection and Preliminary Design / Environmental Impact Assessment phases.

These guidelines are not mandatory, but are recommended in order to achieve consistency with respect to the treatment of geology, hydrology and hydrogeology during the different phases of road scheme planning and design undertaken in accordance with the NRPMG.

The current requirements for EIA are set out in Part IV of the Roads Act, 1993 and Part V of the Roads Regulations, 1994 (S.I. No. 119 of 1994), in particular, Sections 50 and 51 of the Act (as amended). These sections have been subject to significant amendment through the European Communities (Environmental Impact Assessment) (Amendment) Regulations, 1999 (S.I. No. 93 of 1999) and the Planning and Development Act, 2000. Sections 50 and 51 of the Act have been amended further in recent times by the Planning and Development (Strategic Infrastructure) Act, 2006 and the Roads Act, 2007.

More detailed background information on national and European legislation governing the planning, design and implementation of national road schemes is provided in the NRA publication *Environmental Impact Assessment of National Road Schemes – A Practical Guide* (Rev 1, NRA, 2008), together with guidance on the preparation of Environmental Impact Statements for such schemes contained therein.

In addition to the publications identified above, the NRA has also produced a series of Environmental Assessment and Construction Guidelines for National Road Schemes. Those which are of principal interest and relevance to the topics under discussion herein include:

(i) *Guidelines for Assessment of Ecological Impacts of National Road Schemes* (Rev 2, National Roads Authority, 2008) which considers potential impacts of National Road Schemes on natural habitats including surface waters, surface water and groundwater dependent ecosystems, peatlands, exposed rock and disturbed ground;

(ii) *Guidelines for the Assessment of Archaeological Heritage Impacts of National Road Schemes* (National Roads Authority, 2005) which considers potential impacts of National Road Schemes on cultural (human altered) landscapes;

(iii) *A Guide to Landscape Treatments for National Road Schemes in Ireland* (National Roads Authority, 2006) which provides recommendations on managing and mitigating the visual impact of National Road Schemes on the natural landscape;

(iv) *Guidelines for the Crossing of Watercourses During the Construction of National Road Schemes* (National Roads Authority, 2005) which presents recommendations on construction best practice to minimise impacts on natural watercourses and;

(v) *Guidlines for the Management of Waste from National Road Construction Projects* (National Roads Authority, 2008) which examines the issues associated with waste from National Road Schemes.

1.2 National Roads Project Management Guidelines

The key objectives of the NRPMG are to ensure that:

(i) the planning and design of national roads schemes take due account of the potential impact on the existing environment,

(ii) account is taken of all planning and environmental obligations, and

(iii) a consistent, transparent, phased approach is adopted in the planning and design of national road schemes.

The NRPMG identifies four distinct planning phases for a national road scheme.

- Phase 1 involves the overall planning of the schemes, including defining the road need, making provision for the scheme in local development plans, obtaining approvals for subsequent phases of work and appointing consultants.

- Phase 2, the Constraints Study phase, is primarily concerned with the identification of all physical and planning constraints to road development within a defined study area.

- Phase 3, the Route Corridor Selection, involves identification and consideration of alternative routes and selection of a preferred route corridor.

- Phase 4 is the preliminary engineering design and Environmental Impact Assessment phase. As the planning and the design of the scheme progresses through each phase, the area of study reduces and becomes more focused, while the level of detail in the study increases. This approach is summarized graphically in Figure 1-1.

Public consultation, a fundamental requirement of the EIA process, is generally undertaken prior to completion of Phases 2 and 3 outlined above. Should the preferred route corridor differ significantly from one previously advertised at Route Corridor Selection, further public consultation may be undertaken at the outset of Phase 4.

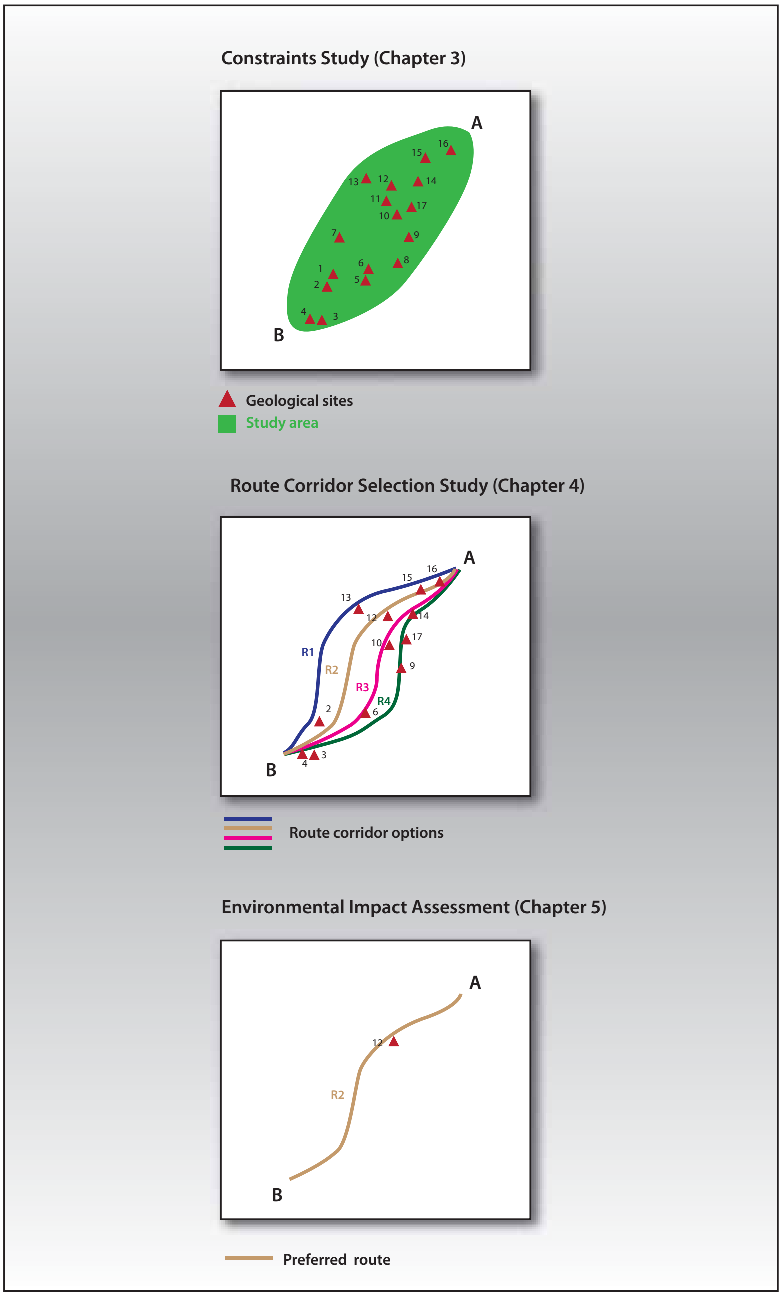


Figure 1-1: *Phases of Planning for National Road Schemes*

1.3 Relevant Legislation

A considerable body of national environmental legislation addresses aspects of the soil and water environment. A general, non-exhaustive, overview of existing legislation is presented in the following sub-sections. Although most legislation deals directly with aspects of the soil and water environment such as ground investigation, water quality or discharges to groundwater, other legislation deals indirectly with aspects such as the protection of sensitive surface water or groundwater dependent ecosystems.

The planning and environmental assessment of National Road Schemes are subject to the provisions of the Roads Act, 1993, as amended. Section 78 of the Roads Act confers powers on a local authority to undertake inspections and site investigations on private lands in connection with the construction and maintenance of public roads or for any purpose incidental thereto. Section 78 provides landowners with a mechanism for claiming compensation for damage suffered as a result of these activities.

1.3.1 Planning and Development Act

Part IV of the First Schedule of the Planning and Development Act, 2000, permits objectives for '*protecting and preserving (either in-situ or by record) places, caves, sites, features or other objects of archaeological, geological, historical, scientific or ecological interest*' and for '*protecting and preserving the quality of the environment, including the prevention, limitation, elimination, abatement or reduction of environmental pollution and the protection of waters, groundwater…*' to be set out in local authority Development Plans.

Drilling and excavation for the purposes of examining the nature and depth of the subsoil is classified as exempted development by Part I of Schedule 2 of the Planning and Development Regulations, 2001 (S.I. No. 600 of 2001), provided it complies with the conditions and limitations applicable to them and with Articles 6 and 9, when appropriate, e.g. provided they don't endanger public safety by reason of traffic hazard. Drilling and excavation within designated or proposed Special Areas of Conservation (SACs), however, are subject to the provisions of the European Communities (Natural Habitats) Regulations, 1997 (S.I. No. 94 of 1997), see Section 1.3.6.

Where a local authority proposes to undertake ground investigations on the foreshore, it must publish a public notice and notify the Minister for Energy, Communications and Natural Resources and prescribed bodies not later than four weeks in advance of commencing the works as required by Section 228 of the Planning and Development Act, 2000 (as amended by Section 45 of the Planning and Development (Strategic Infrastructure) Act, 2006). The local authority must inform the Minister and those bodies of the details of the proposed investigations. The Minister may make recommendations to the local authority and the local authority must have regard to such recommendations when carrying out such investigations. No licence is required under the Foreshore Act, 1933, in respect of any such entry or any site investigations carried out in accordance with section 228.

1.3.2 Water Quality Legislation

The potential to impact on both surface water and groundwater quality is one of the principal issues dealt with throughout this document. Different aspects of water quality are covered by several pieces of legislation. Some of the more relevant legislation is outlined below.

The Local Government (Water Pollution) Acts 1997-1990 provide for the prevention of water pollution in Ireland. Under the Act local authorities have responsibility for ensuring the preservation, protection and improvement of water quality. The Acts include provisions for licensing of discharge of trade effluent and sewage to waters and sewers.

The Local Government (Water Pollution) Act 1977 (Water Quality Standards for Phosphorus) Regulations, 1998, (S.I. No. 258 of 1998) address the problem of eutrophication in surface waters in Ireland and aim to reduce phosphorus losses to water. The Regulations aim to maintain existing quality in rivers and lakes of higher water quality and to improve those of marginal water quality.

Provisions concerning pollution are also contained in the Fisheries Acts, 1959-2003 including those concerning the offence of causing or permitting deleterious matter to enter waters. It is important to note that the Acts define "*waters*" to include both surface water and groundwater bodies.

The European Communities (Quality of Salmonid Waters) Regulations, 1988 (S.I. No. 293 of 1988) give effect to the Council Directive, 1978 (78/659/EEC) (the 'Freshwater Fish Directive'). These Regulations protect scheduled freshwaters by requiring local authorities to adopt action programmes, comprising appropriate measures, to reduce pollution and to ensure that scheduled standards are complied with.

The European Communities (Quality of Shellfish Waters) Regulations, 2006 (S.I. No. 268 of 2006) give effect to the Council Directive 79/923/EEC (the 'Shellfish Waters Directive') on the quality of shellfish waters. These Regulations protect scheduled shellfish waters by requiring the Minister for Communications, Energy and Natural Resources, in consultation with prescribed public authorities, to establish a programme of action with the objective of taking reasonably practicable steps to reduce pollution in scheduled shellfish waters.

The European Communities (Good Agricultural Practice for Protection of Waters) Regulations, 2006, (S.I. No. 378 of 2006) aim to reduce water pollution by nutrients from agricultural sources (livestock manures and other fertilisers). These Regulations give further effect to a number of EU Directives, including Council Directive 91/676/EEC (the Nitrates Directive).

Directive 76/160/EEC (the 'Bathing Water Directive'), as amended, was enacted (S.I. 155 of 1992) to protect the environment and public health by reducing the pollution of bathing water and protected such water against further deterioration. The Directive was transposed by the European Communities (Quality of Bathing Waters) Regulations, 1992-1994, 1996, 1998 and 2001, The Regulations prescribe both bathing water quality standards and the bathing areas to which they apply. The Regulations also prescribe sampling programmes, arrangements for the display of results and the methods of analysis and inspection to be used by local authorities to assess compliance with the standards.

European Communities (Drinking Water) (No.2) Regulations 2007 came into force in 2007 (S.I. No. 278 of 2007). Under these regulations the Environmental Protection Agency (EPA), is the supervisory authority for public water supplies. These regulations provide the EPA with powers of direction to direct a local authority to improve the management or quality of a public water supply while the local authorities have a similar supervisory role in relation to group water schemes and private supplies. The Regulations prescribe standards for 48 individual microbiological, chemical and indicator parameters.

Council Directive 76/464/EEC on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community (the 'Dangerous Substances Directive') prescribe the basic rules on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community. This Directive is strengthened by five daughter Directives that apply to specified substances. Member States are required to eliminate pollution by substances contained in a List I and to reduce pollution by List II substances.

1.3.3 Water Framework Directive

The European Communities (Water Policy) Regulations, 2003, (S.I. No. 722 of 2003*)* transpose Council Directive 2000/60/EC, which establishes an EU wide framework in the field of water policy (the EU Water Framework Directive), into Irish law. For this purpose, the Regulations establish seven River Basin Districts (RBDs), four of which are located entirely within the State (South-Eastern, Eastern, Western and South-Western) and three are Cross-Border/International and shared with Northern Ireland (Shannon, North-Western and Neagh-Bann).

The Regulations require local authorities, to act jointly in relation to each RBD, to establish environmental objectives and programmes of measures for the achievement of these objectives, to make river basin management plans and to establish River Basin District Advisory Councils. They also require co-ordination and guidance to be provided at national level by the Minister and the EPA.

The Regulations also require all public authorities to take appropriate measures within their functional remit to promote or achieve implementation of the Regulations and to co-ordinate, co-operate and liaise with other authorities, including those in Northern Ireland for this purpose.

1.3.4 Flooding Directive

Directive 2007/60/EC on the assessment and management of flood risks (the 'Flooding Directive') came into force on the 27th of November, 2007. Members States have two years in which to transpose the Directive into domestic law. The Directive aims to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity. The Directive requires Member States to first carry out a preliminary assessment by 2011 to identify the river basins and associated coastal areas at risk of flooding. Flood risk maps for these zones then need to be prepared by 2013 and flood risk management plans focusing on prevention, protection and preparedness need to be adopted by 2015.

The Flooding Directive is to be carried out in coordination with the Water Framework Directive, notably in the preparation of flood risk management plans and river basin management plans. It also provides for public participation procedures in the preparation of these plans and requires all assessments, maps and plans prepared to be made available to the public. The Directive requires EU Member States to coordinate their flood risk management practices in shared river basins and to take account of long term developments, including climate change, and sustainable land use practices in preparing flood risk management plans.

1.3.5 Groundwater Directive

The Protection of Groundwater Regulations, 1999, (S.I. No. 41 of 1999), gives further effect to Council Directive 80/68/EEC on the protection of groundwater against pollution caused by certain dangerous substances. (the 'Groundwater Directive'). The Regulations prohibit the discharge of listed dangerous substances to groundwater and provides for control by the Environmental Protection Agency (EPA), by way of a licensing system, of discharges of other such substances by Sanitary Authorities. Section 16 of the Protection of the Environment Act, 2003, further enhances the role of the EPA in licensing discharges to groundwater.

1.3.6 Habitats Directive/Habitats Regulations

Many habitats which are noted for their rare and/or diverse ecology are supported and maintained by the underlying geological strata, surface water inflow and/or groundwater. Where ecological sites are protected by European and Irish environmental legislation, it is essential to understand the existing geological, hydrological and/or hydrogeological environments which support and maintain them.

Habitats relying on hydrological, hydrogeological and geological conditions, which are protected under the Habitats Directive, include: lowland and upland oligotrophic lakes; hard water lakes; natural eutrophic lakes; dystrophic lakes; turloughs; active and degraded raised bog; active blanket bog; transitional mires; cladium fen; petrifying springs; alkaline fen; limestone pavement; caves; and alluvial forests. Species relying on hydrological, hydrogeological and geological conditions, which are protected under the Habitats Directive, include: marsh saxifrage (*Saxafraga hirculus*); Geyer's whorl snail (*Vertigo geyeri*); narrow-mouthed whorl snail (*Vertigo Angustior*); Desmoulin's whorl snail (*Vertigo moulinsiana*); freshwater pearl mussel (*Margaritifera margaritafera*); Nore freshwater pearl mussel (*Margaritifera durrovesis*); white clawed crayfish (*Austropotamobius pallipes*); sea lamprey (*Petromyzon marinus*); river lamprey (*Lampetra fluviatilis*); brook lamprey (*Lampetra planeri*); and Atlantic salmon (*Salmon salar*).

Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (the 'Habitats Directive') is transposed into Irish National Law through, *inter alia*, the European Communities (Natural Habitats) Regulations, 1997-2005 (the 'Habitat Regulations'), the Wildlife Acts, 1976-2000, the Planning and Development Act, 2000, and the Foreshore Acts, 1932-1992.

The Habitat Regulations empower the Minister for the Environment, Heritage and Local Government to designate European sites for the protection of species and habitats annexed under the Habitats Directive. European sites are composed of a number of different types of designated conservation areas including proposed Special Areas of Conservation and Special Areas of Conservation. These European sites represent part of Ireland's contribution to an EU Community network of protected sites (known as NATURA 2000). The Regulations also place an obligation on the Minister, local authorities and other State Bodies to have regard to the provisions of the Regulations in discharging their functions and exercising their statutory powers.

Regulations 14-18 of the Habitats Regulations, 1997, establish a Ministerial consent procedure for any 'operation or activity' being undertaken on any lands within a designated or proposed Special Area of Conservation. Site investigation for the purposes of national road project planning is likely to constitute such an 'operation or activity.' Therefore, it is essential that such activities within a designated or proposed Special Area of Conservation are only carried out after having received the written consent of the Minister of the Environmental, Heritage and Local Government in accordance with Regulation 14.

The principal legislation providing for the protection and conservation of flora and fauna is the Wildlife Act, 1976. The Wildlife (Amendment) Act, 2000, established Natural Heritage Areas (NHA) as the Irish national nature conservation designation and extended protection to features and landforms of geological and geomorphological interest.

Many of the more pristine, less degraded peatlands found in Ireland are afforded protection at a European level as they are designated SACs on ecological grounds under the Habitats Directive. As such, they are not considered for designation as Natural Heritage Areas (NHA's) on geological grounds by the Irish Geological Heritage (IGH) Programme.

Further information on nature conservation legislation is provided in the NRA Guidelines for the Assessment of Ecological Impacts on National Road Schemes *Guidelines for Assessment of Ecological Impacts of National Road Schemes* (Rev 2, National Roads Authority, 2008).

Figure 1-2: *N17 Claremorris By-pass. A localised depression in the bedrock (infilled dissolution feature) was encountered in a steep sided rock cutting developed in horizontally bedded limestone along the N17 Claremorris Bypass. The soil encountered in the steepened side slope was retained behind a wall faced with limestone blocks in order to achieve a uniform geological profile within the rock cutting.*

1.3.7 Heritage Act

The Heritage Council (*An Chomhairle Oidhreachta*) was established by the Heritage Act, 1995. It is an independent body which has a statutory responsibility pursuant to Section 6 of the Heritage

Act, 1995, '*to propose policies and priorities for the identification, protection, preservation and enhancement of the national heritage*'. The Act defines national heritage to include, amongst other things, architectural heritage, landscapes, seascapes, and geology.

Section 2 of the Heritage Act provides a broad definition of archaeology which includes '*the study of, searching and prospecting for … landscapes, seascapes … and climatological, ecological, geological or pedological factors which may be relevant to the understanding of past human societies or the distribution or nature*' of other archaeological features. It also defines landscape as '*areas, sites, vistas and features of significant scenic, archaeological, geological, historical, ecological or other scientific interest' and seascape as 'areas and sites of coastal water including estuaries, bays and lagoons of significant scenic, geological, ecological or other scientific interest*'.

Figure 1-3: *Moyvannan Mushroom Stone, Western shores of Lough Ree, near Athlone. This is a classic mushroom shaped limestone exposure, indicating solution of the rock by a former lake, up to the level of the bottom of the cap. This has been selected by the GSI's IGH Programme as an NHA site exemplifying a rare phenomenon, with only about 60 known in Ireland in total.*

In developing and implementing the National Heritage Plan, it is now Government policy that a County Heritage Officer should be employed by each County Council in order to manage its heritage function in a strategic and co-ordinated manner. Many local authorities have prepared detailed County Heritage Plans which outline their objectives and proposals for conservation and sustainable management of the national heritage. Further information on archaeological conservation legislation is provided in the NRA *Guidelines for the Assessment of Archaeological Heritage Impacts of National Road Schemes* (National Roads Authority, 2005)

1.3.8 Minerals Acts

In Ireland, exploration for, and development of, certain minerals is controlled by legislation, principally the Minerals Development Acts, 1940-1999. Minerals identified in the Schedule to the 1940 Act, such as lead, zinc, copper, gold and coal, are classified as *'Scheduled Minerals'* and can only be developed by obtaining a State Mining Lease/Licence from the Minister for Communications, Energy and Natural Resources. Non-scheduled minerals, which include peat, sand and gravel, limestone, sandstone and other rocks conventionally extracted for use as aggregates and road construction materials, do not require a State Mining Lease.

1.4 Consultees

1.4.1 Statutory Consultees

The statutory consultees in the Environmental Impact Assessment (EIA) process are prescribed under the Roads Act, 1993, as amended, and under associated regulations. For a more complete discussion on the statutory consultees please refer to section 6.1.1 of the NRA's *Environmental Impact Assessment of National Road Schemes – A Practical Guide* (Rev. 1, National Roads Authority, 2008). The statutory consultees at the time of writing are:

- The Minister for the Environment, Heritage and Local Government;
- The National Tourism Development Authority – Fáilte Ireland;
- An Taisce – The National Trust for Ireland;
- An Chomhairle Ealaíon (Arts Council) and the Heritage Council;
- Any local authority, the functional area of which would be affected by the proposed road development;
- The Department of the Environment for Northern Ireland. A copy of the EIS should be sent to the prescribed authority in Northern Ireland where the proposed road development is likely to have significant effects on the environment in Northern Ireland or where the prescribed body so requested;
- In the case of a local authority acting as a road authority (as distinct from the NRA) under section 227 of the Planning and Development Act, 2000, the Minister for Communications, Energy and Natural Resources must be sent a copy of the EIS if any part of a proposed scheme is impacting on the foreshore.

While the Minister for Environment, Heritage and Local Government is a statutory consultee, a copy of the EIS should also be sent to the Development Applications Unit of the National Parks and Wildlife Service, and the National Monuments Section of the DoEHLG.

There is a legal requirement under Section 51(3)(b) of the Roads Act, 1993, as amended, to send a copy of the EIS together with a notice in the prescribed form to the statutory consultees. The notice in the prescribed form should state, *inter alia*, that the authority has made an application for approval of the proposed road development and that submissions may be made in writing to An Bord Pleanála within a specified period in relation to the likely effects on the environment of the proposed road development. Whilst it is a legal requirement to "consult" with the statutory consultees during the EIA stage, the statutory consultees should be approached at an early stage in the national road planning process to inform them of the proposed national road development and to request any relevant information about the existing geological, hydrological or hydrogeological environment. At a later stage, during the preliminary design and EIA stage, the statutory consultees should be re-contacted in order to discuss proposed mitigation measures and the acceptability of any residual impacts.

1.4.2 Non-Statutory Consultees

Apart from the statutory consultees identified above, it may be appropriate to consult a number of Governmental departments and agencies on geological, hydrological or hydrogeological aspects of a proposed national road scheme at an early stage in the planning process to obtain relevant information and ascertain their views in respect of the scheme. These include:

- the Minister of Communications, Energy and Natural Resources (where development may impact on extraction of scheduled minerals);
- Central and Regional Fisheries Boards, Waterways Ireland and/or the Loughs Agency (where development is undertaken in, over or adjacent to the banks of surface waters); and

Other governmental bodies and non-governmental agencies should also be contacted at an early stage to obtain any relevant information which may assist in characterising the existing geological, hydrological and hydrogeological environment and in identifying potential impacts of the road scheme on the local soil and water environments. These include:

- the Geological Survey of Ireland (for geological maps and groundwater well records, to access its karst database, discuss geological heritage);
- Teagasc - the Irish Agriculture and Food Development Authority (for regional subsoil maps);
- Planning authorities (to identify registered pits and quarries and existing / former landfill sites);
- Exploration and Mining Division of the Department of Communications, Energy and Natural Resources (to identify holders of State Mining Licences and obtain mineral prospecting data);
- the Irish Peatland Conservation Council;
- The Mining Heritage Trust of Ireland;

- the Environmental Protection Agency (for details of surface water quality and landfill sites);
- River Basin District Project Offices (for details of surface water and groundwater quality);
- Met Eireann (for climate / rainfall data);
- Local authorities (for details of public water supply schemes and groundwater protection plans);
- Group Water Schemes (to identify source of water supply / source protection area), and
- Local Angling Associations.

More than one environmental consultant will often need to make contact with some of the above-listed agencies and organizations to discuss different aspects of a national road scheme. It is important therefore that the EIA Project Manager coordinates with all relevant environmental consultants to ensure a single, comprehensive consultation is undertaken with the relevant consultee in order to reduce overlap, duplication and scope for future misunderstanding and inconsistency.

1.5 Requirements of Geological, Hydrological and Hydrogeological Consultants

Environmental Impact Assessment (EIA) involves characterizing the existing environment (including its character, context, significance and sensitivity), predicting how it will interact with the proposed development and, where significant adverse impacts are anticipated, devising appropriate mitigation measures with developers and designers.

Expertise, experience, independence and objectivity are all required to deal with geological, hydrological and hydrogeological aspects of EIA. The EPA (2002) advises that environmental specialists involved in EIA should have the following attributes:

(i) knowledge of the specialist topic;

(ii) knowledge of relevant environmental legislation and standards applying to the topic;

(iii) be familiar with standards and criteria for evaluating and classifying significance and impacts;

(iv) be able to interpret documentation produced by the construction sector so that they can understand and anticipate impacts during construction and operation;

(v) ability to work with designers and other specialists to develop practical and reliable strategies to mitigate adverse impacts, and

(vi) be able to present their findings in a clear and comprehensive manner.

For national road schemes, the EIA for the soil and geology, hydrology and hydrogeology topics should be overseen or prepared by suitably qualified and experienced individuals who:

(i) satisfy the criteria outlined above; and

(ii) can objectively demonstrate that they have the required level of specialist knowledge and skill in the relevant topic by reference to qualifications, training and experience.

The NRA recognizes that a significant amount of survey and other work is often required to support geological, hydrological and hydrogeological studies and that it is neither reasonable nor necessary to require that all such works be undertaken or supervised directly by the nominated specialist(s).

Geological, hydrological and hydrogeological specialists must also liaise closely with the engineering design team at EIA stage to ensure their site assessment requirements are adequately addressed in planning, scoping and executing the ground investigation. Refer to Section 5.4 for further general discussion on this topic.

Specialists must also ensure that all aspects of environmental studies undertaken by their team (including fieldwork, testing, reporting etc.) are carried out in accordance with appropriate standards by individuals with an appropriate level of training and expertise. Ideally and insofar as practicable, the same specialist(s) should have a continuous involvement with a national road scheme from its inception (Constraints Study) stage through to Preliminary Design / Environmental Impact Assessment stage.

1.6 Interaction with Other Environmental Consultants

The increased knowledge and appreciation of the potential environmental impact of national road schemes and the complex relationship and interdependence between various environmental media, means that there is an increasing need for specialist consultants undertaking EIA to confer with each other. The Project Manager, the engineering design team and the specialist consultants should liaise where their fields of expertise overlap, to ensure their reports are both complete and consistent.

For national roads projects where EIS sections on soils and geology, hydrology and hydrogeology are prepared by separate Consultants, particular efforts should be made to ensure consistency between them in the presentation of baseline information, assessments and recommendations.

Specific issues to be covered under the Soils and Geology, Hydrology and Hydrogeology topics, which are also addressed by other specialist consultants involved in the EIA process, are identified in Box 1.1.

Box 1.1: Required interaction between consultants

Consultants preparing the Geology, Hydrology (Surface Water) and Hydrogeology (Groundwater) sections of the EIS should liaise with various consultants to ensure consistency on specific issues, including, but not limited to:

Ecologists

- water quality (physio-chemical and biotic) of streams, rivers and other surface water bodies;
- fishery value / classification of streams / rivers and other surface water bodies and
- inputs to wetlands and water dependent ecosystems (quantity and variability).

Agricultural Consultants / Landscape Architects

- soil classification, soil fertility appraisal and assessment of impact of road scheme thereon;
- re-usability of excavated topsoil and subsoil within the proposed road scheme (fertility and ability to support proposed landscape treatments) and
- potential end uses for any topsoil / subsoil removed off-site (specifically disposal and/or recovery).

Archaeologist

- identification and/or investigation of earthworks or landforms laid down or altered by man;
- archaeological potential in particular soil types; and
- mining heritage sites.

Noise and Vibration Specialists

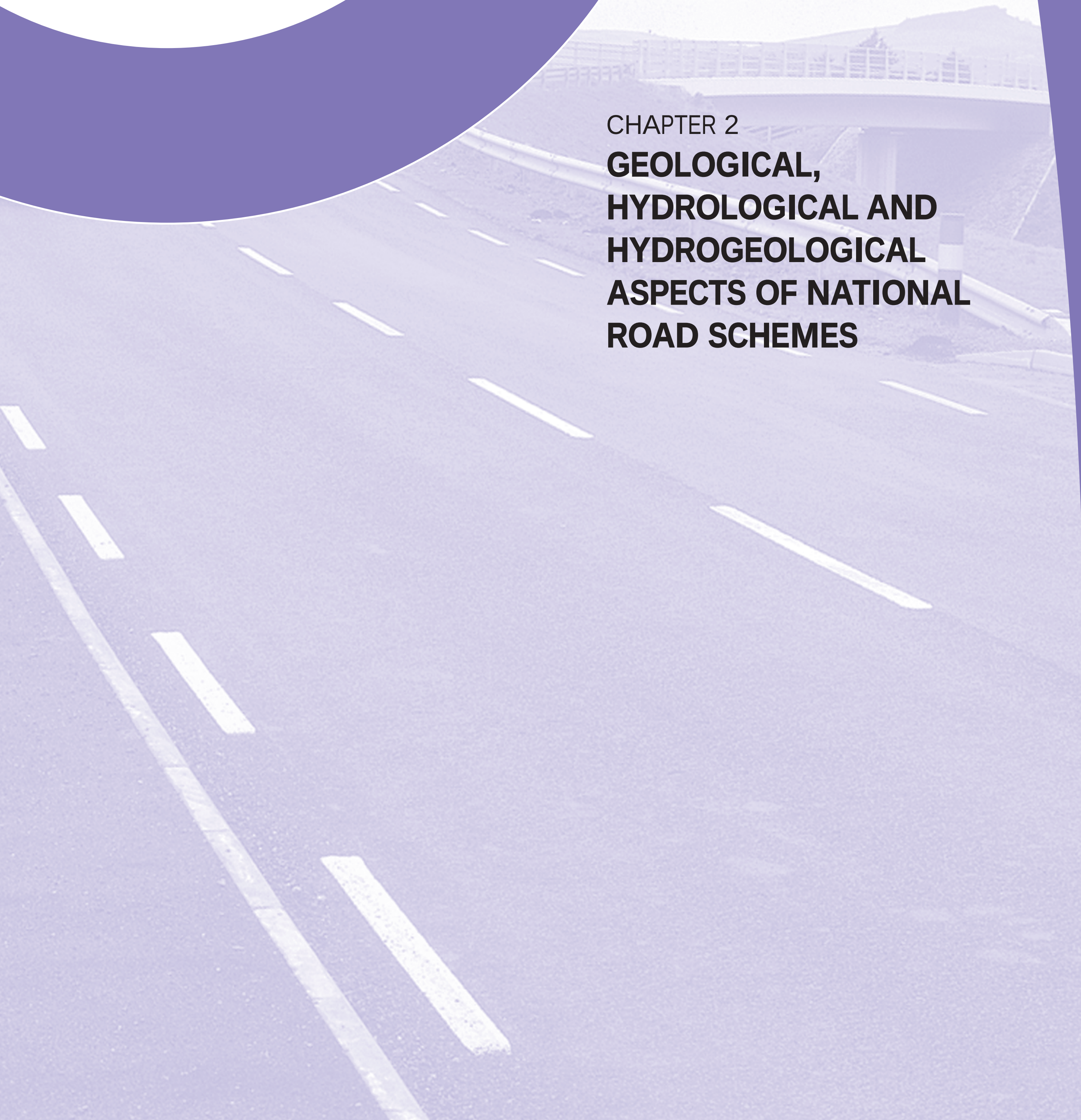
- blast induced noise and vibration in rock cuttings; and
- noise and vibration induced by pile driving at bridge structures.

Economists / Surveyors

- social and economic cost of any increased flood risk at existing properties arising from construction of the proposed road scheme;
- social and economic cost associated with any loss of existing water supply source or reduction in sustainable yield (abstraction rate) and
- social cost associated with any loss of / reduction in amenity value of existing watercourse or surface water body.

CHAPTER 2

GEOLOGICAL, HYDROLOGICAL AND HYDROGEOLOGICAL ASPECTS OF NATIONAL ROAD SCHEMES



2 GEOLOGICAL, HYDROLOGICAL AND HYDROGEOLOGICAL ASPECTS OF NATIONAL ROAD SCHEMES

In Ireland in the recent past, the impact of development on the earth's surface and sub-surface has generally tended to recieve limited attention in Environmental Impact Statements. This may arise in part because Section 50(3)(b) of the Roads Act, 1993, as amended, refers only to 'soil' and 'water' and does not explicitly identify 'geology' or 'hydrogeology' as topics to be addressed by the Environmental Impact Assessment process. This situation has been partially redressed, however, by the *Guidelines on Information to be Contained in an Environmental Impact Statement* published by the Environmental Protection Agency (EPA) (2002), which includes 'geology' under the 'soils' heading and 'groundwater under the 'water' heading.

Figure 2-1: *N4 Mullingar Bypass. The road cutting along the N4 Mullingar Bypass exposed a superb anticline fold in the Carboniferous limestones. As traffic enters the cutting, limestone beds dip one way and then level out at the top of the cut before dipping away in the opposite direction. This excellent visible demonstration of simple geological phenomena such as beds and folds was for a period rendered invisible by roadside planting.*

2.1 Geological Aspects

All construction projects, including national road schemes, are constructed in, or on, the geological environment. A wide range of geologically related issues therefore affect the planning and construction of roads. Soil properties determine whether it can be re-used in construction of earth structures. Bedrock properties determine how it is excavated and its subsequent value and use as a construction material. In some limestone areas, the presence of karst features requires specific construction responses to ensure safety and stability of the road.

Figure 2-2: *Sinkhole in a closed depression in a lowland karst area caused by collapse of soil or rock in a fractured or cavernous limestone area.*

2.1.1 Soil

Soil acts as an interface between the earth, air and water. Soil (*pedosphere*) is connected to, and responds to, the atmosphere, climate, ecosystems (*biosphere*), sub-surface (*lithosphere*), surface water and groundwater (*hydrosphere*).

Fertile agricultural soils which are used for agriculture and food production can take thousands of years to evolve and are essentially non-renewable. In the near future, the potential development of biofuels and/or biomass as sources of alternative energy are likely to place increased pressure on the earth's productive soil resource, displacing established agricultural and food production activities. The competing demands of the biofuel / biomass and food industries are likely to increase the environmental and economic value of productive soils and increase public awareness that soil resources, like all earth resources, are finite.

Figure 2-3: *Variable sand and gravel stratigraphy exposed in quarry in eastern Ireland. These sediments were formed during glaciation and are typical of the glacial deposits found throughout Ireland particularly in the midlands region.*

In general, the environmental and socio-economic impacts associated with the irreversible loss of fertile, productive soils and ground sealing along a national road scheme are likely to be relatively minor, even at a local level. However, changes to soil systems can also impact on other environmental media and the hydrological cycle. Where such impacts are likely and significant, they should be identified and assessed in the planning and design of national road schemes.

2.1.2 Economic Geology

Almost everything that is made or built, and much of the energy we use, emanates from the Earth. Metals, industrial minerals, construction materials, oil and gas are extracted from the earth's crust. However, as many of these resources are finite and non-renewable, there is increasing appreciation of the need to prevent sterilization of known mineral / aggregate resources, promote sustainable use of such resources and achieve a better balance between land-use, development and environmental management.

Ireland has a wide range of geological resources, principally metalliferrous or industrial minerals and construction aggregates, which are at various stages of identification and development. While some deposits have been identified and fully extracted, others have only recently been discovered and have yet to be developed. Others have yet to be discovered. In general, national road schemes should seek to avoid sterilising known mineral or aggregate reserves which are currently being exploited, or could potentially be, at some point in the future.

2.1.3 Geohazards

'Geohazards' are, in essence, natural Earth processes that pose a risk to human life. They can range from geological hazards such as landslides, bog-bursts, coastal erosion or subsidence to hydrometerological hazards like floods and high tides. For national road schemes, it is important that such hazards be identified at preliminary road planning stage and avoided, where possible, in order to eliminate risks to construction personnel and prospective road users. Failing this, hazards should either be minimized and human vulnerability to them reduced. In addition to natural hazards, the engineering design of a national road scheme must also have regard to the stability of cut slopes, earth structures and foundations.

2.1.4 Geological Heritage

Geological strata, and the fossilized plant and animal remains preserved within them, are one of the most valuable records of the origin and evolution of life on Earth, of historical changes in climate and early human history.

The advent of global warming in recent decades and the increased awareness of its potential impact on the planet's future has meant that it is becoming increasingly important to understand past climatic variability so that we can better understand the relative influence of human activity and natural processes on climate. While existing climatic records only extend back a few hundred years, geological exposures and investigations have the potential to reveal how climate change has impacted the Earth in the past and its implications for living creatures.

For national road schemes, it is important to ensure that the best and potentially most valuable examples of our geological heritage are preserved and/or recorded, to simultaneously assist us in understanding the Earth's past and predicting its future.

Figure 2-4: *The Derrylea mine site, about 5km east of Clifden, Co. Galway was identified as at risk from the re-alignment of the N59. A comprehensive study by the Mining Heritage Trust of Ireland assessed its importance and recorded the site. Although the mid-19th century mine adits were very short and not deemed of sufficient importance to redesign the road away from a very constrained pinch point, the study revealed a wealth of associated industrial heritage which was not recorded on any historical maps.*

From: Parkes, M. Duffy, P. and Critchley, M. 2006. Assessment of Derrylea Mine, County Galway. Galway's Mining Heritage: Extracting Galway. Proceedings of a Conference, 26th August 2006, 9-24.

2.1.5 Geomorphology

Geomorphology is the study of the landforms which comprise the Earth's surface, the processes which have modified and shaped it in the past and which continue to modify and shape it at the present time. While the Irish natural landscape has largely been sculpted by the most recent ice-age, it is dynamic and undergoes continuous change, with weathering and erosion being driven by climatic agents such as wind, temperature and precipitation, as well as by surface drainage systems and fire.

Often the changes in the natural landscape occur so slowly, they are barely perceptible over generations. On rare occasions, as in a landslide event, change can occur suddenly and catastrophically. In planning and designing national road schemes, it is important to identify and understand the geomorphological processes which shape and change the natural landscape over time and to consider if and how such processes may be impacted upon by the proposed scheme.

2.1.6 Made Ground / Landfills

Made Ground is a term which refers to materials (typically waste) which have been deposited on, in or under land or natural soils which have been altered by man, or a combination of both. Materials deposited on, in or under land may have been placed in a controlled manner, in accordance with an engineering specification, or in an uncontrolled manner, often by casual end-tipping of unsorted material. Made Ground typically occurs at or around historic or present-day human settlements, at poorly drained agricultural lands, around historic or present day industrial, mining or quarry sites and along infrastructure networks (roads, pipelines etc). Given its uncertain composition and origin, there is a risk that Made Ground may be contaminated, though this can only be conclusively established by site specific ground investigations.

There are numerous historical municipal, industrial and/or commercial landfill sites across Ireland. Most of the older, unlicensed landfills were operated by local authorities or industrial enterprises and located close to town or village settlements or industrial sites. Many of these older landfills were poorly engineered and constructed on peat, poorly drained land or in abandoned quarries. Records of historical landfills can be patchy and unreliable and these sites are often only identified following consultations with landowners and /or retired local authority staff.

Notwithstanding the fact that arrangements for the authorisation of waste facilities has been in place in Ireland since 1997, a number of unauthorised (illegal) landfill facilities did operate across the country in the late 1990's and early 2000's. In recent years, efforts have been made by the Office of Environmental Enforcement to identify these unauthorised facilities and to compel landowners to undertake a programme of remediation.

In planning and designing national road schemes, it is critically important to identify areas of recently reclaimed ground, historical landfill sites and existing waste disposal or recovery facilities in order to minimize the potential financial and environmental risks to the scheme.

2.1.7 Construction Materials

Soil and rock differ from all other environmental media considered in the Environmental Impact

Assessment process in that they are construction materials as well an environmental receptor. It is not, therefore, possible to completely decouple the environmental impact assessment of a national road scheme on soil and geology from the engineering design of the scheme. For national road schemes, road designers can promote more sustainable development and reduce environmental impacts on soil and geology by:

- maximizing the re-use of excavated materials;
- minimizing the import of construction materials;
- minimizing off-site waste disposal, and
- reducing related construction impacts (such as noise, dust, traffic movements, etc.).

This is best achieved by sourcing earthworks materials and construction aggregates either along the scheme or in close proximity to it and similarly, by disposing of or recovering excess materials generated by the scheme either along or in close proximity to it.

2.1.8 Construction Stage Impacts

Where soils are excavated and/or stored for re-use during construction, they are prone to erosion by surface water run-off and may degrade the aquatic environment. They may be compacted by earthmoving machinery, reducing its ability to store water and support vegetation, leading to increased run-off and erosion. In addition, there may be a loss of valuable seed banks when soil is removed from sites of ecological heritage value. These temporary construction stage impacts should be identified and assessed as part of the geological impact assessment for national road schemes.

Guidance on the classification, selection, treatment and management of excavated soils for landscaping purposes are provided in the NRA publication *A Guide to Landscape Treatments for National Road Schemes in Ireland* (2006).

More detailed background information in respect of the Irish geological environment and the issues identified above is presented in Appendix A of these Guidelines.

2.2 Hydrological Aspects

Hydrology is the study of the water environment (hydrological cycle) and surface water bodies (rivers, estuaries, ponds/lakes and reservoirs) with which man and animals have the greatest interaction. It is estimated that about 95% of all the water in the hydrosphere is contained in the oceans and seas. Of the fresh water resources of the Earth (estimated to be about 5% of the total water), the frozen proportion stored in the form of snow, ice and permafrost has been estimated as about 75% of the total. Only about 1% of the total water in the hydrosphere is readily available for exploitation by humanity. Of the available water, about 99% is in the form of groundwater and about 1% in the form of surface water stored in lakes and rivers and as soil moisture.

2.2.1 Hydrological Cycle

The hydrological cycle is the concept used to explain the exchange of water between the Earth and its atmosphere and is illustrated in Figure 2-5.

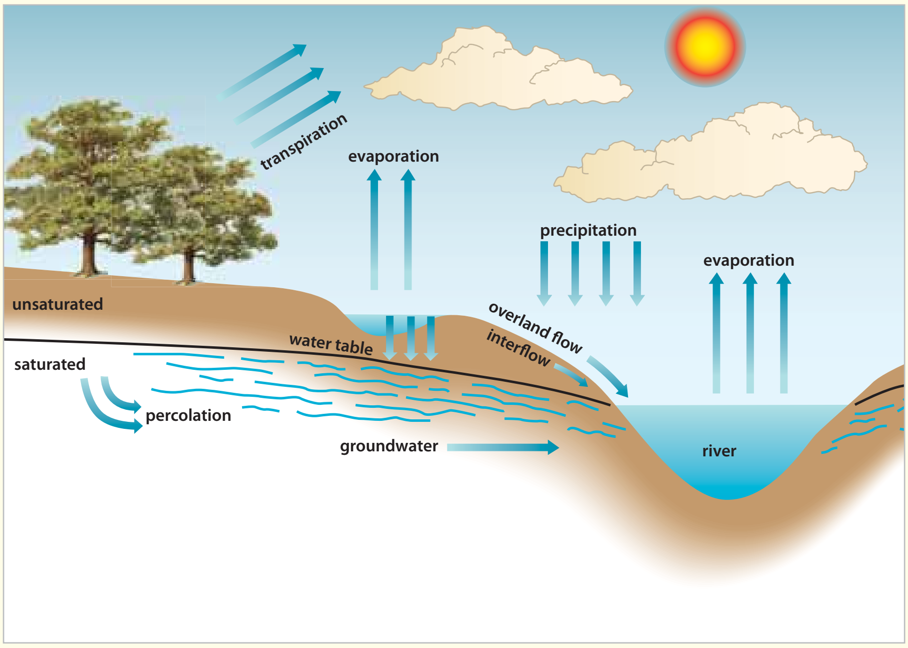


Figure 2-5: *The Hydrological Cycle*

This exchange, which is on-going all the time, is powered by the heat of the sun (solar radiation) and the pull of gravity. The hydrological cycle begins with the evaporation of water from the oceans, surfaces such as wet ground, the leaves of plants and from lakes and reservoirs. The resulting vapour is transported by moving air masses. The vapour condenses to form clouds, which may result in precipitation in the form of rain, hail or snow. The precipitation which falls on the land is dispersed in different ways. A significant part is temporarily retained in the soil near where it falls, and is ultimately returned to the atmosphere by evaporation and transpiration by plants. Some of the water finds its way over and through the near surface soil horizons, to stream and river channels, while the remainder penetrates further into the ground to become part of the earth's groundwater resources. The main components of the hydrological cycle are, therefore, precipitation, interception, evaporation, transpiration, infiltration and run-off.

2.2.2 Climate Change

Climate is defined as 'the average weather experienced in a region over a long period'. It is now acknowledged by almost all climate scientists that average global temperatures are currently rising and that the emission of greenhouse gases (principally carbon dioxide) by human activities is the principal cause. As a result of global warming, the Earth's climate will change and it is expected that over the next 100 years, Ireland will experience significant changes in rainfall characteristics and increased sea levels around the coast. Increased sea levels will increase the risk of coastal flooding and also lead to higher water levels upsteam in river estuaries.

Climate change, and specifically the implications for the design of drainage systems, needs to be addressed by environmental specialists and engineering design teams involved in planning and design of national road schemes. Sufficiently robust environmental and engineering drainage solutions must be developed to deal with predicted future river flows.

Given the variability in the predicted impacts of climate change across the country and the variability in hydraulic characteristics of drainage catchments, it is not feasible to provide universally applicable guidance as to how climate change impacts should be quantified and provision made for these in drainage design. At the present time, both the Greater Dublin Strategic Drainage Study and the UK Highways Agency publication 'Road Drainage and the Water Environment' (HA216/06) adopt a pragmatic approach to climate change by recommending that the sensitivity of the drainage design to a factored increase on present day rainfall depths for all durations and return periods is established and, where necessary, provision for same is made in drainage design.

2.2.3 Flooding

Historically, flooding has been a major concern in Ireland for centuries. Aside from extreme rainfall events, a number of other factors may contribute to flooding in different areas. In karstified limestone lowlands, flooding is often related to a rise in the level of the water table. In other areas, flash flooding may be attributed to low soil permeability and topography within a local river catchment. Flooding is often associated with urbanisation, which leads to a large increase in volume and intensity of surface water run-off within a given catchment. The encroachment of urban development onto existing flood plains can lead to a reduction in flood storage capacity, with a resultant increase in flood risk both upstream and downstream.

Construction of a national road scheme will affect the flood response of the catchment(s) within which it is located. The increase in impervious area means that a greater proportion of the incident rainfall will appear in the drainage system as surface run-off. The provision of sealed pipes (as used in areas of karstified limestone) to convey run-off from the road to existing watercourses will result in larger (concentrated) volumes being discharged at point locations within a shorter duration, thereby increasing flood risks. Road embankments may encroach onto existing floodplains and lead to a reduction in flood storage capacity, exposing property owners and ecosystems living within or near the floodplain to an increased risk of flooding. Bridge piers may be constructed in existing river channels and alter the established flow regime.

2.2.4 Surface Water Quality

The chemistry and quality of river waters is generally a reflection of geology and landuse (specifically diffuse agricultural and urban run-off and point discharges from industrial facilities and municipal wastewater treatment plants). The main effects of pollution on the quality of river water are a reduction in dissolved oxygen (deoxygenation) and nutrient enrichment (eutrophication).

Water quality assessment of surface waters in Ireland is based on data collected from both physico-chemical and biological surveys. Physico-chemical surveys involve taking river water samples and analysing them for specific parameters as well as examining samples of sediment from the bed of the river or stream. Biological monitoring of rivers is based on the relationship between water quality and the relative abundance and composition of the macro-invertebrate communities in the sediment of rivers and streams. The greater the diversity, the better the water quality.

Construction of road crossings (culverts / river underbridges) or discharges to watercourses give rise to a number of potential impacts on water quality and fisheries, the most notable of which are the increased pollution risk from surface run-off during construction, accidental spillage of fuel and discharge of road run-off drainage.

Re-sectioning or re-aligning river channels has the potential to affect the geomorphological processes which control river habitats and can, therefore, have indirect impacts on water quality and fisheries upstream or downstream of the affected section of channel. Guidance on bridge and culvert design and construction is provided in the NRA publication *Guidelines for the Crossing of Watercourses during the Construction of National Road Schemes*.

2.2.5 Resource and/or Amenity Value

Construction of a national road may alter the established drainage pattern and the volume of run-off to surface waters used for water supply or amenity purposes. The scheme may interfere with access to an established amenity site or lessen the enjoyment of leisure activities such as fishing, boating or riverside walks. These impacts, if significant, should be addressed by the Environmental Impact Assessment for the scheme.

More detailed background information in respect of the Irish hydrological environment and the issues identified above is presented in Appendix B of these Guidelines.

2.3 Hydrogeological Aspects

Hydrogeology deals with groundwater and the underground (or geological) part of the hydrological cycle. Groundwater is intimately connected to the atmosphere, soils, climatic processes, watercourses, surface water bodies and the oceans. Rainfall infiltrates the ground and moves as recharge to the groundwater table, thereafter flowing by different pathways until it discharges either to a surface water body (including rivers, lakes and fens), a spring, a well or the ocean. Along the way, the water passes through five distinct horizons below the ground surface, specifically:

- Topsoil;
- Organic and/or mineral subsoils (Quaternary deposits);
- Interface between subsoil and bedrock;
- Shallow bedrock and
- Deeper bedrock.

In terms of the hydrological cycle, groundwater can act as a long-term storage for water, with residence times from days to millennia.

2.3.1 Aquifers

An aquifer is defined as a geological formation that is capable of yielding significant quantities of water. Aquifers generally consist of clean, coarser geological materials where permeability has developed in response to a variety of geological processes. There are a variety of aquifer types in Ireland. Limestone, dolomite, sandstone and volcanic strata are bedrock aquifers and sands and gravels are unconsolidated aquifers. The interpretation of 'significant' yield varies widely – it can range from a supply of 50,000m^3/day for a city or large industry, down to 500m^3/day for a domestic supply or small farm. On this basis, most rock types are aquifers: however, their sustainable yield (supply) encompasses a broad range. The term aquitard refers to poor aquifers or unproductive rocks that have little throughput and which are generally only capable of giving low yields to wells.

Geological strata are classified for hydrogeological purposes as either Major (Regionally Important) Aquifers, Minor (Locally Important) Aquifers or Unproductive Rocks (Poor Aquifers / Aquitards). The Geological Survey of Ireland further sub-divides the aquifer categories on the basis of aquifer type (bedrock or sand and gravel) and a qualitative assessment of the dominant flow type.

Figure 2-6: *Heavily karstified limestone face exposed in a quarry in eastern Ireland. Note the variable depth of dark brown glacial till overlying rock on left hand side of the photograph. Note also the sub-vertical and sub-horizontal nature of discontinuity enlargement and infilling. Karst features are often infilled with soil of Tertiary age (>1.8 million years old). The occurrence of such soils is relatively rare in Ireland (most having been eroded by successive ice ages).*

Vulnerability is the term which applies to the intrinsic geological and hydrogeological characteristics which determines how readily groundwater becomes contaminated by human activities. The vulnerability of groundwater depends on the travel time of the infiltrating water (and contaminants), the quantity of contaminants and the attenuation capacity of the geological materials through which the water and contaminants infiltrate. These in turn are a function of the natural geological and hydrogeological characteristics such as:

- the type and thickness of subsoils that overlie the groundwater body;
- type of contaminant recharge (point or diffuse);
- the thickness of the unsaturated zone through which the contaminant moves, and
- the hydraulic conditions (i.e. confined or unconfined).

In general, the greater the thickness of low to medium permeability subsoil deposits (clay/silt), the greater protection from potential contaminants is afforded to the underlying groundwater resource.

In assessing the hydrogeological impact of a national road scheme, the aquifer classification and its vulnerability should be considered along the full length of the alignment. Hydrogeological impacts on aquifers will be controlled to a significant degree by the vertical alignment of the road and the underlying geological profile. As the vertical alignment is scheme specific and geological / hydrogeological environments vary significantly across Ireland, it is not possible to provide guidance which addresses every conceivable design scenario. As such, professional judgement must be applied when assessing the impact of national road schemes on aquifers.

2.3.2 Groundwater Quality

Groundwater quality is normally a function of anthropogenic (human) influences; however, groundwater quality can also be poor because of natural features such as elevated iron, manganese or fluoride levels. The quality of many groundwaters has been impacted by elevated nitrate concentrations, which has originated through poor agricultural and wastewater management practices. The concentration of contaminants in groundwater is influenced largely by proximity to source and the vulnerability of the aquifer.

Construction of national road schemes gives rise to a number of potential impacts on groundwater quality, the most notable of which are the increased pollution risk from untreated surface water run-off, accidental spillage of fuel and road run-off drainage. These implications need to be addressed by environmental specialists and engineering design teams involved in planning and design of national road schemes.

2.3.3 Groundwater Supply

Although it exists everywhere beneath the Earth's surface, the value of a groundwater resource is largely dependent on local rainfall conditions (recharge) and the reservoir characteristics of the underlying soil and/or rock. Provided there is adequate replenishment and it is protected from pollution, groundwater can be abstracted and used as a resource indefinitely.

Figure 2-7: *Traditional wells and handpumps, found across the Irish rural landscape. These wells were generally located close to urban areas or busy road junctions.*

Groundwater from springs, dug wells and boreholes is a reliable and relatively inexpensive source of freshwater and provides supplies for domestic, industrial and agricultural use. In Ireland, groundwater is the source for over 25% of the total public and private drinking water and in certain rural areas of the country, it provides up to 85% of the drinking water supply (EPA Water Quality in Ireland 2001-2003, Toner *et al*., 2005). Beyond the local authority or Group Water Schemes, water supplies for individual houses and farms are provided almost exclusively by low yielding boreholes, dug wells or springs/seeps. It is estimated that there are of the order of 200,000 such wells in Ireland. At the present time, the majority of private water supplies remain untreated. In addition to conventional supply wells, there are also small springs in some areas that are referred to as '*holy wells*' which can be of local cultural significance.

Groundwater can also be an important component of river and stream flow in areas of major aquifers and during dry periods in late spring, the summer and early autumn, groundwater baseflow can constitute almost the entire flow in some rivers.

In planning and designing a national road scheme, a thorough assessment should be made of the impact of the scheme on any high-yielding springs and wells used for public water supply and their surrounding protection zones. An assessment should also be made of the impact on lower-yielding wells used for domestic and farm water supplies.

2.3.4 Groundwater Ecosystems

In Ireland, groundwater supports many different types of wetland habitats which are noted for their rare and/or diverse ecology. Many of these sites are protected by European and Irish environmental legislation. They include deposits from calcium rich groundwaters which formed low permeability marls on which fen peat wetlands developed and are sustained. They also include turloughs, which principally occur in the west of Ireland, and which are essentially controlled by the inflow and outflow of groundwater.

Wetland habitats may be sensitive to relatively minor changes in groundwater levels, recharge and other meteorological factors. Construction of a national road scheme may give rise to changes in groundwater level and have an impact on recharge to groundwater dependent ecosystems. These effects, where significant, should be addressed by the Environmental Impact Assessment.

2.3.5 Karst

Karst environments are valued for several reasons. They contribute large volumes of water to river baseflow, they are often important sources of water supply, they support distinctive groundwater dependent habitats and they contain cave systems which provide a distinctive habitat for flora and fauna, often contain archaeological remains and are used for leisure pursuits (caving) or developed as tourist attractions (showcaves).

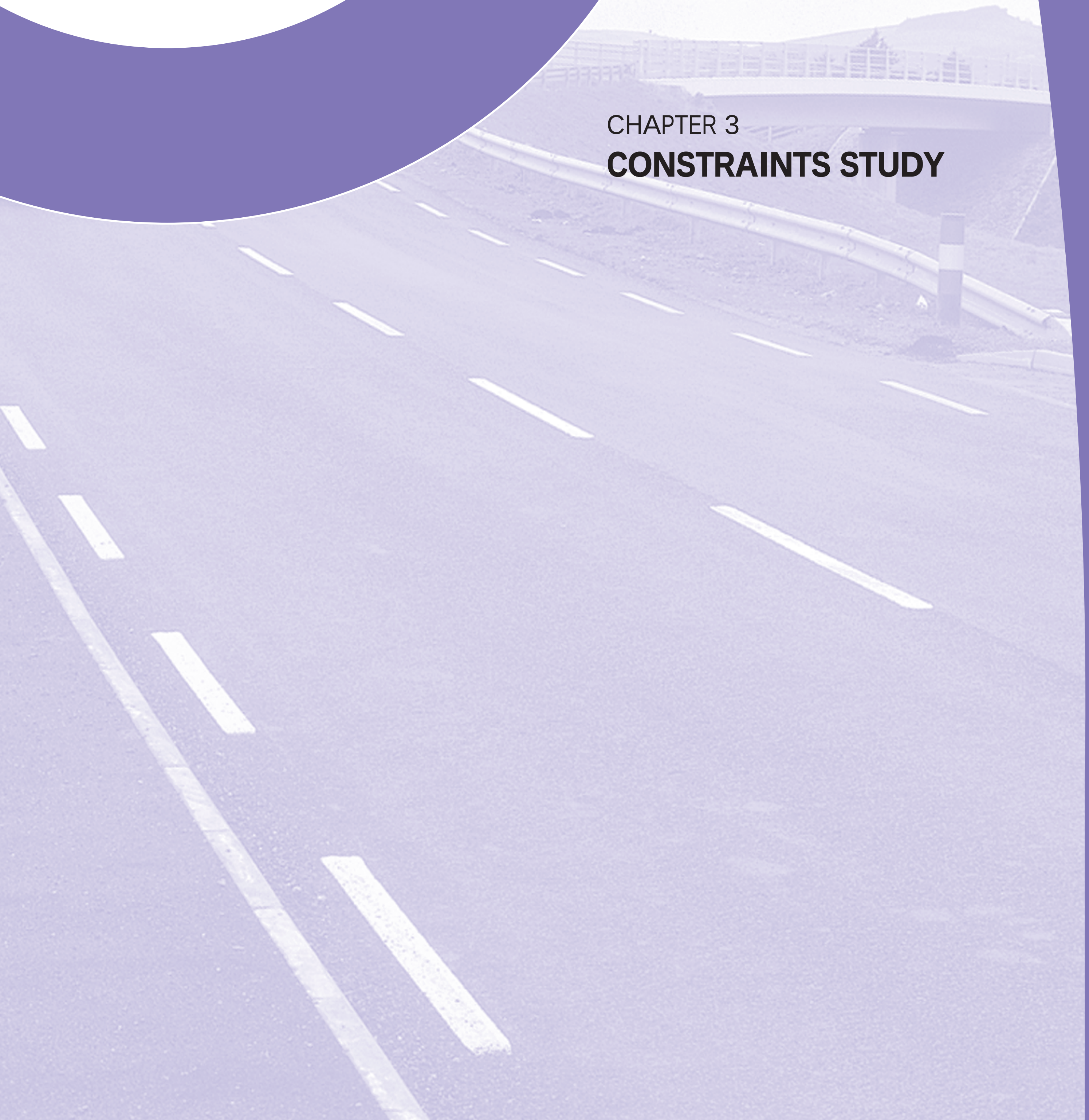
Figure 2-8: *A turlough is a seasonal lake which forms in a karst area when groundwater level rises above ground level. The photographs above illustrate the changes which occur between summer and winter months.*

Historically, karst hydrogeology has been associated with the limestone uplands of Ireland, where large river cave systems are found. By comparison, the karst of the Irish lowlands tends to be of a less grand scale, and includes features such as dolines (closed depressions), stream sinks, turloughs and occasionally caves. These features tend to act as point inputs of surface water to groundwater. Often in the Irish context, and specifically in the lowland setting, a mantle of subsoil covers the limestone surface. Turloughs, which are almost unique to Ireland, have a water chemistry which supports many unusual freshwater flora and fauna. (Refer to NRA *Guidelines for Assessment of Ecological Impacts of National Road Schemes* (Rev 2, National Roads Authority, 2008)). The construction of national road schemes in karst environments presents significant environmental challenges, particularly with respect to protection of karst hydrogeological features, groundwater quality and sensitive groundwater-fed ecosystems.

More detailed background information in respect of the Irish hydrogeological environment and the issues identified above is presented in Appendix C of these Guidelines.

Figure 2-9: *Sheshymore, Co Clare. This area of limestone pavement is identified as perhaps the best example of this landform, which is more often considered simply as a rare habitat for plants. Sheshymore is already protected as an SAC, but is highlighted as a geological treasure by the IGH Programme of the GSI.*

National Roads Authority
An tÚdarás um Bóithre Náisiúnta



CHAPTER 3

CONSTRAINTS STUDY

3 CONSTRAINTS STUDY

3.1 Objective

Constraints studies are undertaken at the outset of the road planning and design process. The principal objective of such studies as defined in NRPMG is to identify at the earliest opportunity:

(i) all environmental constraints (be they human, natural, physical, social or economic) within a defined study area, which ideally should be avoided by the proposed road scheme, and

(ii) all technical or environmental issues that could potentially impact on:

a. the planning and design of the scheme;

b. give rise to increased costs and/or

c. delay progress in delivering the scheme.

The information obtained at the Constraints Study stage informs subsequent decisions about feasible route corridors and selection of a preferred route corridor. It is also used to describe the existing environment at a general scale when preparing the Environmental Impact Statement for the road scheme.

3.2 Approach

Much of the information required to prepare the geological, hydrological and hydrogeological sections of the Constraints Study can be obtained by means of desk based studies. This essentially involves identifying and retrieving relevant published information on the geology, hydrology and hydrogeology of the defined study area.

Consultations should be initiated with statutory consultees and relevant Government agencies, local authorities and non-governmental organizations at this stage in order to confirm official designations and legislative requirements in respect of protected sites, surface waters and aquifers.

The findings of the desk based study and consultations are collated and presented in the Constraints Study Report. Ideally all data acquired during the Constraints Study should be compiled and managed on a Geographical Information System (GIS) database.

3.3 Methodology

3.3.1 Collection of Baseline Information

The initial work to be undertaken during the Constraints Study is to identify and retrieve readily available geological, hydrological and hydrogeological information in respect of the study area. Sources of information to be consulted at this stage are identified in: ; and Table 3.1: Sources of Geological Information; Table 3.2: Sources of Hydrological Information and Table 3.3: Sources of Hydrogeological Information.

	SOILS AND GEOLOGY
Bedrock Geology	1:100,000 Scale Bedrock Mapping (Geological Survey of Ireland)
Karst Features	Karst Database (Geological Survey of Ireland)
Subsoils	Quarternary Maps (Geological Survey of Ireland)
	Teagasc Subsoil Mapping (2004)
Soils	General Soil Map of Ireland (An Foras Talúntais, 2nd Edition, 1980)
	The Peatlands of Ireland (An Foras Talúntais, 1981)
	Teagasc Soils Mapping (2007)
Economic Geology: Pits and Quarries	Directory of Active Quarries, Pits and Mines in Ireland (Geological Survey of Ireland, 3rd Edition, 2001)
	Planning Departments of Local Authorities (Section 261, Planning and Development Act 2000)
	State Mining and Prospecting Facilities (published twice annually by Exploration and Mining Division of DCENR)
	Concrete Products Directory (Irish Concrete Federation)
Geological Heritage	Proposed / Designated NHA Sites (Geological Survey of Ireland)
	National Parks and Wildlife Service
	County Geological Sites (Local Authority Planning Office/Heritage Officers)
	Mining Heritage Trust of Ireland (old mining sites)
Landfills Contaminated Sites	Office of Licensing and Guidance, Environmental Protection Agency http://www.epa.ie/
	Local Authorities (Waste Management Section)
	Historical Maps (Ordnance Survey of Ireland / National Library of Ireland)
	Also at http://www.irishhistoricmaps.ie/
Geomorphology	National Landslide Database (Geological Survey of Ireland)
	Aerial Photographs (Geological Survey of Ireland / Ordnance Survey of Ireland)
	Atlas of Ireland (Royal Irish Academy)

Table 3.1: *Sources of Geological Information*

	HYDROLOGY
Surface Water Features	1:50,000 Discovery Series Maps (Ordnance Survey Ireland)
	1:10,560 Maps (Ordnance Survey Ireland)
Catchments	Rivers and their Catchment Basins, Map by Ordnance Survey (1958)
	River Basin Management Projects (http://www.wfdireland.ie/)
	Local Authorities (Environment Section)
River Flows	Hydrometric Section, Office of Public Works (www.opw.ie)
Flooding	Engineering Services Section, Office of Public Works
	Flooding Records at National Flood Hazard Website http://www.floodmaps.ie/
EPA	Water Quality
Public Water Supply	Local Authorities (Water Supply Section) Group Water Schemes

Table 3.2: *Sources of Hydrological Information*

	HYDROGEOLOGY
Aquifers	EU Water Framework Directive website at http://www.wfdireland.ie/
	National Draft Bedrock Aquifer Map (Geological Survey of Ireland)
	National Draft Gravel Aquifer Map (Geological Survey of Ireland)
	Draft Interim Vulnerability Map (Geological Survey of Ireland)
Public Water Supplies Group Water Schemes	Local Authorities (Water Supply Section)

Table 3.3: *Sources of Hydrogeological Information*

3.3.2 Reporting

Having collected and collated the available baseline data, a Constraints Study Report should be prepared for each topic. This report should present the available data, briefly discuss any implications for route corridor selection and present summary baseline maps, including one identifying all relevant constraints.

The outline contents of Constraints Study Reports for Soils and Geology, Hydrology and Hydrogeology are presented in Sections 3.4, 3.5 and 3.6.

3.4 Contents of Constraints Study Report (Soil and Geology)

The Soil and Geology section of the Constraints Study Report should present information under some or all of the following headings:

- Introduction;
- Methodology – to include a brief statement of how the Constraints Study was prepared. Include details of the data sources, consultations undertaken, limitations in methodology and data quality, gaps in data;

- Where relevant the implications of the various constraints on the route corridor selection stage should be discussed;
- Geomorphological Study – briefly describe existing landforms within study area and processes shaping and altering the landscape. Identify potential geohazards to be avoided at the route corridor selection stage. An overview of the principal components of a geomorphological study is presented in Box 3.1.
- Overview of Solid Geology – discuss possible implications for route corridor selection stage. In karst limestone areas, identify any known karst features, including any areas of limestone pavement;
- Overview of Subsoil Deposits – identify potential soft ground areas;
- Overview of Soil Deposits – identify if wide or limited range of agricultural use and drainage characteristics;
- Contaminated Land – identify all known landfill sites (licensed and historical) and other sites within study area which could potentially have contaminated soil (former industrial facilities, disused mines pits and quarries);
- Economic Geology – identify location, and provide details of, all active quarries, pits and mines in study area and known (or likely) mineral / aggregate resource areas;
- Geological Heritage – identify and include details of designated and/or protected sites within the study area;
- Inventory of Geological Constraints – to identify type, location (by Townland, Electoral Division and County) and Irish National Grid Co-ordinates for each constraint identified;
- References/List of Information Sources;
- Glossary, and
- Figures/Maps.

Maps accompanying the Soil and Geology section of the Constraints Study Report should be based on the 1:50,000 scale Discovery Series map of the study area and the immediate vicinity and should include:

- Bedrock Geology Map (identifying karst areas / hydrogeological features, where present);
- Subsoil Deposits Map (identifying soft ground deposits and Made Ground areas), and
- Geological Constraints Map (including landfills, contaminated sites, quarries, heritage sites and geohazards).

Notes should be placed on bedrock and subsoil maps to advise that the extent of the various soil and rock deposits indicated are only approximate and that the information provided can only be verified by ground investigation at a later stage.

Box 3. 2: Geomorphological Studies

Geomorphology is the study of the landforms which comprise the Earth's surface, the processes which have modified and shaped them in the past and which continue to modify and shape them at the present time.

The principal geomorphological processes are erosion and deposition and these are driven by ice, wind and water. During the last glacial period, the surface of Ireland was shaped by the processes of ice and water. Landforms such as moraines, drumlins, corries, glaciated valleys and kames were formed by the moving ice, while deltas, glacio-fluvial outwash deposits, meltwater channels and eskers were all formed by meltwater associated with the ice sheets. At the present time, the surface of Ireland continues to be modified by water and rivers, and in coastal areas by tides and wind.

At the Constraints Study stage, a preliminary geomorphological study should be undertaken of the study area, based primarily on aerial photography and the information sources identified above. The study should identify and describe the terrain units within the study area which have essentially similar geological, hydrological and hydrogeological characteristics (e.g. bogs, karst limestone pavement, alluvial plains, glaciated lowlands etc.) Thereafter, individual landforms and/or geomorphological processes may be identified within each terrain unit. Examples of landforms and/or processes for different terrain types are presented below:

- *Glacial:* Moraines, Drumlins, Kettle holes, Kames;
- *Periglacial:* Pingos, Soliflucted slopes;
- *Glaciofluvial:* Outwash deposits, Meltwater channels, Deltas, Eskers;
- *Fluvial:* River Channels, Ox-bow lakes, Palaeochannels, River Terraces, River Floodplains or Callows;
- *Karst:* Sinkholes, Springs, Dolines, Turloughs; and
- *Coastal:* Dunes, Coastal Erosion, Sand bars.

The value of a geomorphological study at this stage is that it identifies:

- the relationship between geology (rock and subsoils) and different types of terrain;
- potential geohazards, most notably areas of historical or ongoing instability (inculuding landslides), subsidence and areas of reclaimed or filled ground;
- dynamic river banks, subject to ongoing erosion and/or deposition; and
- dynamic estuaries and/or coastlines, subject to ongoing erosion and/or deposition.

If potential geohazards and dynamic landforms are identified by a geomorphological study, these should be noted in the Constraints Study Report and, where appropriate, subject to further investigation during subsequent stages of road planning and design.

Figure 3-1: *Exposure of Glacial Till along eroding coastline in South-East Ireland.*

3.5 Contents of Constraints Study Report (Hydrology)

The Hydrological section of the Constraints Study Report should present information under some or all of the following headings:

- Introduction;
- Methodology – to include a brief statement of how the Constraints Study was carried out. Include details of the data sources, consultations undertaken, limitations in methodology and quality, gaps in the data;
- Where relevant, the implications of the various constraints on the route corridor selection stage should be discussed;
- Geomorphological Study – briefly describe existing drainage regime within study area and any processes affecting watercourses or surface water bodies. Identify areas of potential river bank, estuarine or coastal instability to be avoided at the route corridor selection stage;
- Surface Water Features – identify all principal surface water features within study area. Note the presence of any lakes, surface water impoundments and weirs/locks in river channels. Note also the existence of tidal and/or river tidal effects;
- Catchments – define catchment and sub-catchment geomorphology in terms of surface area, drainage pattern, topography and likely run-off characteristics;
- Flooding - identify areas known to be liable to flooding and extent of river floodplains;

- Surface Water Resources - identify rivers, lakes and reservoirs used for water supply for local authority or Group Water Schemes. Identify known surface water abstraction sites. Identify any provisions in County Development Plans to protect surface water bodies used for supply purposes;

- Ecology – consult with the ecologist to identify aquatic habitats which may be sensitive to changes in water level or water quality. Identify and include details of designated and/or protected areas (NHAs, SACs, salmonid waters, shellfish waters etc.). Cross reference ecological section of Constraints Study Report, and

- Inventory of Hydrological Constraints - to identify type, location (by townland) and Irish National Grid Co-ordinates for each constraint identified.

Maps accompanying the Hydrology section of the Constraints Study Report should be based on the 1:50,000 scale Discovery Series map of the study area and the immediate vicinity and should include:

- Surface Water Features and Catchment Map (identifying abstraction points and associated source protection areas, where defined), and

- Hydrological Constraints Map (include ecologically sensitive water bodies, unstable river banks and flood risk areas).

3.6 Contents of Constraints Study Report (Hydrogeology)

The Hydrogeological section of the Constraints Study Report should present information under some or all of the following headings:

- Introduction;

- Methodology – to include a brief statement of how the study was carried out. Include details of the data sources, consultations undertaken, limitations in methodology and quality, gaps in the data;

- Where relevant the implications of the various constraints on the route corridor selection stage should be discussed;

- Aquifer Type and Classification – identify the geological strata within the study area, describe and classify the aquifer properties of these strata (i.e. Regionally Important, Locally Important or Poor Aquifer) and discuss possible implications for the route corridor selection stage. Cross reference the Soil and Geology section of the Constraints Study Report;

- Karst – identify if any limestone strata within the study area are prone to karstification. Identify the main characteristics of the karst environment and any known karst features;

- Vulnerability – identify groundwater vulnerability of the aquifers within the study area;
- Groundwater Resources – identify any large springs, holy wells and groundwater sources for Local Authority, commercial / industrial or Group Water Schemes within the study area. Identify any established source protection areas within the study area;
- Ecology - consult with the ecological specialist to identify and describe any groundwater dependent habitats within the study area. Cross reference the ecological section of Constraints Study Report; and
- Inventory of Hydrogeological Constraints - to identify type, location (by Townland, Electoral Division and County) and Irish National Grid Co-ordinates for each constraint identified.

Maps accompanying the Hydrogeology section of the Constraints Study Report should be based on the 1:50,000 scale Discovery Series map of the study area and the immediate vicinity and should include:

- An Aquifer Map (identifying karst areas / hydrogeological features, where present);
- An Aquifer Vulnerability Map, and
- A Hydrogeological Constraints Map - to include locations of any major springs and water supply boreholes, groundwater dependent habitats and known hydrogeological or karst features. (This map should also include the extent of any known Source Protection Areas within the study area).

Figure 3-2: Water *level monitoring in surface water body*

Consult Available Information
(Geology, Hydrology and Hydrogeology)
(e.g. geological, aquifer and historical mapping,
karst database, local authorities, Office of Public Works,
Department of Communications, Energy and Natural Resources, etc.)

↓

Prepare Inventory of Constraints
(Geology, Hydrology and Hydrogeology)
To be verified and supplemented during Public Consultation
and Route Corridor Selection Study

↓

Prepare Constraint Maps
(Geology, Hydrology and Hydrogeology)
Information obtained during the Constraints Study

↓

Compile Constraints Report
Include inventory of constraints, explanatory text

Figure 3-3: *Flowchart showing Constraints Study (Phase 2)*

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An tÚdarás um Bóithre Náisiúnta

CHAPTER 4

ROUTE CORRIDOR SELECTION

4 ROUTE CORRIDOR SELECTION

4.1 Objective

At route corridor selection, a number of feasible route corridors are developed taking account of all physical, planning and environmental constraints identified by the Constraints Study Report. The route corridor selection involves undertaking a comparative evaluation of the route corridors, having regard to multiple factors in order to identify a preferred route corridor.

The specific geological, hydrological and hydrogeological impacts associated with each route corridor are identified as part of the comparative evaluation. Insofar as is practicable, any significant or unacceptable impacts on soils and geology, surface water or groundwater environment should be avoided when selecting the preferred route corridor. Route corridor selection is the single most effective means of avoiding or minimizing unacceptable environmental impacts.

Notwithstanding this it should be recognized that the optimum route corridor from a geological, hydrological or hydrogeological perspective may not be the overall optimum corridor when other environmental, social or economic impacts are taken into account. In deciding the overall optimum route corridor, potential impacts on soil and geology, surface water and groundwater have to be balanced against other factors including, though not limited to, engineering constraints, traffic, cost and impact on residential amenity, communities, leisure use, ecology, agriculture, cultural heritage and landscape.

As the various components of the natural, cultural and built environment can vary markedly at local or regional level, it follows that the route corridor selection process will be different for each national road scheme. Each scheme will have its own unique set of constraints and different weightings will attach to the various potential environmental impacts. For example, for some schemes, hydrogeological impacts such as the construction of deep cuttings in major productive aquifers, may exert a heavy weighting on the overall evaluation of route corridors, whereas for others, where the underlying aquifer(s) may be poor and/or only locally productive, the weighting of potential hydrogeological impacts is likely to be lower.

4.2 Approach

The information required to prepare the geological, hydrological and hydrogeological sections of the Route Corridor Selection Report is obtained by:

(i) supplementing the desk study information obtained during the Constraints Study phase with any further readily retrievable data specifically relating to the route corridors, including the examination of any locally relevant information or data;

(ii) use of stereoscopic aerial photographs to identify previously unmapped soft or disturbed ground, potential geohazards or hydrogeological features in the vicinity of the route corridors;

(iii) a targeted drive-by (windshield) survey, if appropriate, along route corridors to verify (or 'ground truth') the available data and identify any unrecorded changes in the landscape associated with more recent human activity (eg. filled ground, recent drainage works, diverted watercourses), and

(iv) field inspections of important sites and features identified at Constraints Study stage which are likely to be of geological, hydrological or hydrogeological significance in order to assess the significance of any likely environmental impacts on them (eg. geological heritage features, springs, swallow holes, large supply wells).

At Route Corridor Selection, it should be appreciated that the proposed route corridors are indicative linear corridors which require more focused study than that undertaken over the wider study area for the previous Constraints Study phase. At this stage, it must be appreciated that there is still scope at a future stage, during the EIA process, to alter the horizontal and vertical alignment of the proposed road within the defined corridors.

When undertaking geological, hydrological and hydrolgeological studies at Route Corridor Selection, it is recommended that the study area should encompass an overall width of 500m, i.e. 250m from the centre line of each route corridor. The study area may need to be extended where the footprint of the proposed road scheme extends outside of this area, for example along link roads and/or re-aligned side roads. In such instances, the study area should also extend a similar distance (250m) beyond the road centre line.

Notwithstanding this, some professional judgement must be applied in assessing whether the study area around a particular road corridor needs to be extended to take account of potentially significant impacts which could arise a greater distance away (eg. at groundwater dependent SAC/NHA sites which could be hydraulically connected over an extended distance to groundwater in a proposed road cutting).

Further consultations should be undertaken with statutory consultees, relevant government agencies and non-governmental organizations at this stage to seek their views on the merits of the various route corridors and any specific local issues which may be known or of concern to them (including recent or prospective changes in land-use, site designations or site boundaries or proposals for future drainage works or water supply schemes).

Throughout the Route Corridor Selection stage, geological, hydrological and hydrogeological consultants should liaise with each other as well as with the engineering design team and other environmental consultants, particularly in respect of scope of any preliminary investigations and potential interactions between environmental receptors.

Preliminary ground investigation work may be undertaken at Route Corridor Selection where it is considered that:

- significant geological, hydrological or hydrogeological impacts could arise if one or more route corridors were to proceed to construction stage, and

- it is necessary to establish, with some degree of confidence, the magnitude of such impacts prior to identifying an emerging preferred route.

Some guidance on the scoping of preliminary ground investigations is provided in Section 4.3.3.

The findings of any further desk based study work, field surveys (visual, non-intrusive and/or intrusive) and consultations are collated and presented for each route corridor in the Route Corridor Selection Report. The geological, hydrological and hydrogeological impacts associated with each route corridor are identified, assessed and compared and then ranked in order of preference. Ideally any additional data acquired during the Route Corridor Selection Study should be compiled and managed on a Geographical Information System (GIS) database.

4.3 Methodology

4.3.1 Collection of Additional Data

Information gathered at the Constraints Study phase will provide the baseline information for studies undertaken at the route corridor selection phase. During the Route Corridor Selection Study, more detailed geological, hydrological and hydrogeological information should be sought and compiled.

Along the proposed route corridors, the 1:50,000 geological maps compiled during the Constraints Study may be supplemented with data from the original (c. 1860) Manuscript Field Maps and publications (memoirs) from the Geological Survey of Ireland. Aerial photographs should be examined to identify potentially unmapped landfill and contaminated sites in close proximity to any of the proposed route corridors which should be the subject of a field inspection. Should any existing quarries, pits or mines be located in close proximity to any of the route corridors(within 500m), the operator should be approached to establish the present day footprint of the quarry (which may be greater than that indicated on maps or aerial photographs), to determine land ownership and identify potential future resource areas where extensions to existing operations may be sought.

Hydrological information may be supplemented with additional data or publications from the Office of Public Works, the River Basin Management Projects, the Environmental Protection Agency and the Electricity Supply Board. Hydrogeological information may be supplemented with information from hydrogeological reports and the groundwater database of the Geological Survey of Ireland. Additional information on the extent and nature of any karst features in close proximity to any of the proposed route corridors can be obtained from a variety of academic or technical publications and specialist caving publications.

4.3.2 Field Surveys : Visual Inspections

A cursory inspection and field survey may be warranted at important sites and features identified along route corridors to verify (or 'ground truth') information compiled from desk based studies or the Public Consultation process at Constraints Study Stage.

If appropriate, the opportunity can be taken during field surveys or Public Consultations to speak with landowners and people living locally about events and changes which may have occurred in the landscape in recent memory. Useful information can often be obtained in this way on geological, hydrological and hydrogeological features and issues including land reclamation works, landfilling, burial sites for diseased cattle, stream diversion or arterial drainage works, seasonal flooding, abandoned wells or pollution incidents etc.

A brief inspection of principal crossings of rivers and larger streams should be undertaken along each of the proposed route corridors. These inspections should identify or confirm the location of any control measures such as dams, weirs or locks and any effluent discharge or water abstraction points. The extent of existing flood plains in the vicinity of principal crossings along the proposed route corridors should also be inspected and confirmed.

4.3.3 Field Surveys : Ground Investigation

If it is considered that significant environmental impacts could arise at critical geological, hydrological or hydrogeolgical sites where the available information is insufficient to establish the likely magnitude of such impacts, then consideration should be given to procurement of a preliminary ground investigation. The scope of such an investigation should have regard to the following factors:

- the nature, extent, importance and sensitivity of the site/feature being investigated;
- the underlying solid and quarternary geology;
- the inferred hydrogeological regime (based on available desk based study information); and
- the probable vertical alignment of the route corridor (cutting or embankment).

As preliminary ground investigations are often procured for engineering purposes at this stage of the planning process, the opportunity to undertake additional ground investigations for environmental purposes should be considered. It is imperative that the requirements for, and scope of, such investigations are discussed and agreed with the road design team.

Where possible, ground investigations undertaken at Route Corridor Selection should use appropriate non-invasive, geophysical survey techniques (such as seismic refaction or electrical resistivity) to determine stratigraphy, depth to bedrock or presence of groundwater. Guidance on appropriate geophysical techniques may be sought from the CIRIA publication 'Geophysics in Engineering Investigations (CIRIA C562) or from a specialist geophysical Contractor.

If geophysical survey techniques are likely to be impractical or insufficiently conclusive, it will be necessary to use some basic invasive techniques such as trial pits, boreholes, cone penetration testing (CPTs) or rotary drilling (percussive or coring) to establish the ground profile and groundwater conditions.

In planning and scoping preliminary ground investigations, consideration should be given to the following:

(i) Trial pits can be scheduled at suspected contaminated or backfilled locations along, or in close proximity to, route corridors. Should any evidence of buried non-inert wastes be identified in the trial pits, soil samples should be taken and tested in accordance with requirements of Council Decision 2003/33 establishing criteria and procedures for the acceptance of waste at landfills;

(ii) Dynamic probes, window sampling, cone penetration tests (CPT) and/or boreholes can be scheduled at peat or soft ground sites where it is necessary to assess the extent and depth of material to be excavated and replaced;

(iii) Boreholes and rotary drillholes can be scheduled where it is necessary to establish the nature, depth and thickness of sand and gravel or bedrock aquifers and the associated hydraulic conditions (ie. unconfined, leaky or confined);

(iv) Particle size distribution tests on disturbed samples can provide an approximate estimate of soil permeability (*provided* care is taken to minimize loss of soil fines during sampling);

(v) In-situ permeability tests in boreholes or drillholes can be scheduled to determine the field permeability of soils and/or rock, and

(vi) Groundwater instruments can be installed in completed boreholes or drillholes to measure variations in water level over time (and identify flow direction and hydraulic gradient).

As the findings of the ground investigation could be critical for the selection of the preferred route corridor, it is important that it be attended and supervised by a competent member of the Consultant's / Designer's team.

4.4 Impact Assessment of Route Corridors

In order to assess the relative merits of each of the identified route corridors from a geological, hydrological or hydrogeological perspective, it will be necessary to assess the likely impact each route will have on the respective geological, hydrological or hydrogeological attributes along each route.

The assessment of likely impacts at route corridor selection stage will largely be undertaken using information obtained from desk based studies and field surveys. In assessing likely impacts, due account should be taken of both the importance of the attributes (see Boxes 4-1, 4-2, 4-3) and the predicted scale and duration of the likely impacts (see Box 4-4).

For each route corridor, a summary of the associated impacts for each topic should be clearly presented in a tabular format. An example of how a geological impact assessment might be presented for a particular route corridor is presented in Table 4.1. In this example, the evaluation for each of the geological attributes identified along a particular route corridor option and the level of impact of the route corridor on them are decided by reference to Box 4-1 and Box 4-4 respectively.

ROUTE CORRIDOR B			
Attribute	**Attribute Importance**	**Impact**	**Level of Impact**
Threefaces Quarry	High	Sterilisation of small proportion of future reserves at a large quarry site	Moderate negative
		Proximity to proposed route corridor	Minor positive
Ardcoill Rock Exposure	High	Partial loss of interest feature at County Geological Site	Moderate negative
Ballybeg C+D Landfill	Medium	Small proportion of C+D waste at large landfill site to be excavated during construction	Minor negative
Agricultural Soils – Entire Route	Low	Loss of low fertility soil over high proportion of route	Minor negative
Peat / Soft Ground – Entire Route	Low	Very small volume of soft ground requiring excavation	Neutral

Table 4.1: *Preliminary Assessment of Soil and Geology Impacts for Route Corridor B*

As only very limited engineering design is undertaken on the route corridors and as site specific information is not generally available at this stage, much of the preliminary impact assessment will be of a qualitative rather than a quantitative nature. A significant degree of professional judgement will therefore be required in identifying and rating likely environmental impacts.

The assessment should take account of environmental mitigation measures that can be implemented and this should be clearly stated. However, at Route Corridor Selection, it is not necessary to develop mitigation measures.

4.4.1 Soil and Geology Impacts

For the soil and geology topic, the attributes (and impacts) to be assessed for each route corridor may include the following:

- geological heritage sites along each route corridor;
- landfills, backfilled quarries or former industrial sites along each route corridor and the potential risk of encountering contaminated ground;
- the quality, drainage characteristics and range of agricultural uses of soil along each route corridor;
- pits, quarries or mines in the vicinity of each route corridor, the potential implications (if any) for existing activities and future extractable reserves, and

- the extent of peat and soft ground along each route corridor and the potential requirement to excavate it and remove it off-site as waste for disposal or recovery.

In assessing the impact of a route corridor on a designated geological heritage site (NHA), it is important to bear in mind that management issues for geological heritage sites can differ significantly from ecological sites, and in some cases road development may actually facilitate enhanced geological understanding of a site by exposing more rock sections in (say) a new road cutting.

4.4.2 Hydrological Impacts

Most of the potential environmental impacts for watercourses occur close to the points where the proposed route corridors cross the water channel, aside from the potential to cause flooding both upstream and downstream and reduce water and biological quality downstream.

For the hydrology (surface water) topic, the attributes (and impacts) to be assessed for each route corridor may include the following:

- watercourses crossed by each route corridor and potential impact on water quality arising from re-alignment works and discharge of surface water run-off;
- aquatic ecological sites close to and downstream of water crossings;
- surface water abstraction close to and downstream of water crossings;
- established amenity value of surface waters traversed by each route corridor, and
- potential increase (or reduction) in flood risk to existing properties.

4.4.3 Hydrogeological Impacts

For the hydrogeology (groundwater) topic, the attributes (and impacts) to be assessed for each route corridor may include the following:

- high yielding water supply springs and wells along each route corridor and increased risk presented by the road scheme;
- the classification (regionally important, locally important, poor) and extent of aquifers underlying each route corridor and increased risks presented to them by the road scheme (associated with aspects such as removal of subsoil cover, removal of aquifer (in whole or part), drawdown in water levels, alteration in established flow regimes, change in groundwater quality);
- natural hydrogeological / karst features along each route corridor and the increased risk presented by the road scheme, and
- groundwater fed ecosystems and the increased risk presented by the road scheme.

Figure 4-1: *Sinkhole at Polliniska Cave, on the border of Counties Cavan and Fermanagh*

Note that in addition to assessing the potential impact of a route corridor on water supply springs or natural hydrogeological features, it is also necessary to assess the potential impact on their protection zone or zone of contribution. These zones can extend up to several kilometres, mainly upgradient, of the supply source or feature. If these have not been defined previously, an initial attempt should be made to define them at route corridor selection stage.

Low yielding wells, used mainly for domestic and farm water supply, are very common in Ireland outside the watermains networks of urban centres. In the absence of a comprehensive well survey along each of the route corridors, little or no weighting should be given to the number of wells along each route corridor and/or their distance from the route centre line when assessing relative impacts. It is almost inevitable that any large national road scheme will result in at least a small number of low-yielding water supply wells having to be abandoned. In the case of low-yielding water supply wells, ranking of the level of potential impact is unnecessary, as wells will either have to be replaced or not.

4.5 Comparison of Route Corridors

Having undertaken an impact assessment for each route and identified the number of impacts at each level, the results should be summarised in tabular format similar to that presented in Table 4.2. Summarising impacts in this way allows an order of preference for route corridors to be established from a geological, hydrological and/or hydrogeological perspective.

Where two route corridor options have a similar number of likely impacts, then the route which affects the greater number of high value attributes (as determined using the criteria presented in Boxes 4-1 to 4-3) should be considered the least preferred option.

TOPIC : SOILS AND GEOLOGY			
Impact Level	Route Corridors		
	Route Corridor A	Route Corridor B	Route Corridor C
Severe Negative	0	0	0
Major Negative	1	0	1
Moderate Negative	1	2	1
Minor Negative	3	2	2
Neutral	0	1	1
Minor Positive	0	1	0
Order of Preference	3rd	1st	2nd

Table 4.2: *Summary of Soil and Geology Impacts for Route Corridor Options*

In general for each topic, the route with the lowest predicted impact will be identified as the preferred Route Corridor while that with the greatest predicted impact will be the least preferred. A route corridor with a number of relatively minor impacts may be preferable to one which has just one severe impact. Balancing the relative direct and indirect impacts for a number of sites requires significant professional judgement. In the interests of transparency, it is essential that the reasoning applied in rating the impacts and ranking the route corridors is explained in detail in the Route Corridor Selection Report.

As previously noted, the optimum route corridor from a geological, hydrological or hydrogeological perspective may not be the overall optimum corridor when other environmental, social or economic impacts (e.g. ecology or archaeology) are taken into account.

4.6 Contents of Route Corridor Selection Report (Soil and Geology)

The Soils and Geology section of the Route Corridor Selection Report should be prepared using desk based study information (including aerial photography), feedback from consultees and findings from any field surveys undertaken. The report should present information (where available) in the format outlined below:

- Introduction;
- Methodology – to include a brief statement of how the Route Corridor Study was prepared, with details of data sources, consultations undertaken, field surveys, impact assessment, comparison of route corridors, limitations in methodology and gaps in data;
- Overview of Solid Geology, Subsoils and Soils along Route Corridors - to include any additional information obtained from desk study, aerial photographs and field surveys (including ground investigations);
- Overview of Ground Conditions and Features in Karst Limestone Areas along each route corridor;
- Overview of Historical Land Use along each route corridor;

- Overview of Economic Geology along each route corridor;
- Overview of Geological Heritage along each route corridor;
- Impact Assessment – to identify and rate, in the context of the road proposal, all likely significant impacts affecting soils and geology along each route corridor;
- Comparison of Route Corridors – to include detailed outline of the reasoning applied in ranking the route corridors;
- References / List of Information Sources;
- Glossary, and
- Figures / Maps.

Maps accompanying the Soils and Geology section of the Route Corridor Selection Study should be based on 1:50,000 scale Discovery Series mapping and should superimpose the route corridors under review on a:

- Bedrock Geology Map (identifying karst areas, geological resource areas and heritage features, where present);
- Subsoils Map (identifying soft ground deposits, Made Ground, contaminated ground, geological resource areas, heritage features and geohazards, where present); and
- Soils Map.

Notes should be placed on bedrock, subsoil and soil maps to advise that the extent and accuracy of the various soil and rock deposits indicated are only approximate and that the information provided can only be verified by detailed ground investigation at a later stage.

4.7 Contents of Route Corridor Selection Report (Hydrology)

The Hydrology section of the Route Corridor Selection Report should be prepared using desk based study information (including aerial photography), feedback from consultees and findings from any field surveys undertaken. The report should present information (where available) in the format outlined below:

- Introduction;
- Methodology – to include a brief statement of how the Route Corridor Study was prepared, with details of data sources, consultations undertaken, field surveys, impact assessment, comparison of route corridors, limitations in methodology and gaps in data;
- Overview of Catchments and Sub-Catchments crossed by each route corridor;
- Overview of Flows in watercourses crossed by each route corridor;
- Overview of Drainage Issues along each route corridor – identify drainage characteristics and any predominant drainage problems. Areas known to have been drained in the past

should be noted (identifiable from historical mapping), together with any artificial watercourses / channels built for industrial purposes (e.g. milling, distilling);

- Overview of Flooding Aspects and Floodplains along each route corridor;
- Overview of Surface Water Quality along each route corridor – present baseline data on the water quality of each significant watercourse or lake in the vicinity of route corridors.
- Overview of Water Supply Sources along each route corridor;
- Overview of Abstractions from Surface Water along each route corridor – identify any Group Water Schemes, municipal or industrial abstraction points;
- Overview of Discharges to Surface Water along each route corridor - identify any existing municipal sewage effluent discharges and other industrial / licensed discharges to streams or rivers which may impose a constraint on the quality of the surface / road runoff;
- Overview of Ecological Issues along each route corridor. Cross reference the Ecological section of the Route Corridor Selection Report;
- Classification of the scale and importance of the watercourse crossings along each route corridor, whether by pipe, culvert, bridge or tunnel (form of structure determines the likely impact on the watercourses crossed by route corridors);
- Impact Assessment – to identify and rate, in the context of the road proposal, all likely significant impacts affecting surface waters along each route corridor;
- Comparison of Route Corridors- to include detailed outline of the reasoning applied in ranking the route corridors;
- References / List of Information Sources;
- Glossary, and
- Figures / Maps.

Maps accompanying the Hydrology section of the Route Corridor Selection Study should be based on 1:50,000 scale Discovery Series mapping and should superimpose the route corridors under review on a:

- Surface Water Features and Catchment Map (identifying stream order, abstraction and discharge points and the extent of any pre-defined Source Protection Areas for surface waters);
- Drainage and Flooding Map, and
- Surface Water Quality Map.

4.8 Contents of Route Corridor Selection Report (Hydrogeology)

The Hydrogeology section of the Route Corridor Selection Report should be prepared using desk based study information (including aerial photography), feedback from consultees and findings from any field surveys undertaken. The report should present information (where available) in the format outlined below:

- Introduction;
- Methodology – to include a brief statement of how the Route Corridor Study was prepared, with details of data sources, consultations undertaken, field surveys, impact assessment, comparison of route corridors, limitations in methodology and gaps in data;
- Overview of Aquifer Type and Classification along each route corridor. Cross reference Soil and Geology section of Route Corridor Selection Report;
- Overview of Aquifer Characteristics along each route corridor - describe the provenance (source) and type of permeability in the main aquifers and provide indicative values for permeability, transmissivity, storage and specific capacity (if readily available). Outline the hydraulic conditions (unconfined, leaky or confined) in each of the aquifers and comment on the possible presence of artesian conditions in any strata;
- Overview of Groundwater Resources – Identify any high yielding groundwater sources for local authority water supply, Group Water Schemes or commercial / industrial purposes along each of the proposed route corridors. Identify also any source or aquifer protection schemes along each of the proposed route corridors;
- Overview of Hydrogeological Features - identify any wetland habitats, springs and holy wells along each of the proposed route corridors;
- Overview of Karst Areas and Karst Features along each route corridor;
- Overview of Aquifer Vulnerability along each route corridor;
- Impact Assessment – to identify and rate, in the context of the road proposal, all likely significant impacts affecting groundwater along each route corridor;
- Comparison of Route Corridors - to include detail outline of the reasoning applied in ranking the route corridors;
- References / List of Information Sources;
- Glossary, and
- Figures / Maps.

Maps accompanying the Hydrogeology section of the Route Corridor Selection Study should be based on 1:50,000 scale Discovery Series mapping and should superimpose the route corridors under review on:

- an Aquifer Map;
- an Aquifer Vulnerability Map, and
- a Hydrogeological Features Map (to include major springs and water supply boreholes, wetland areas, karst / hydrogeological features and pre-defined Source Protection Areas).

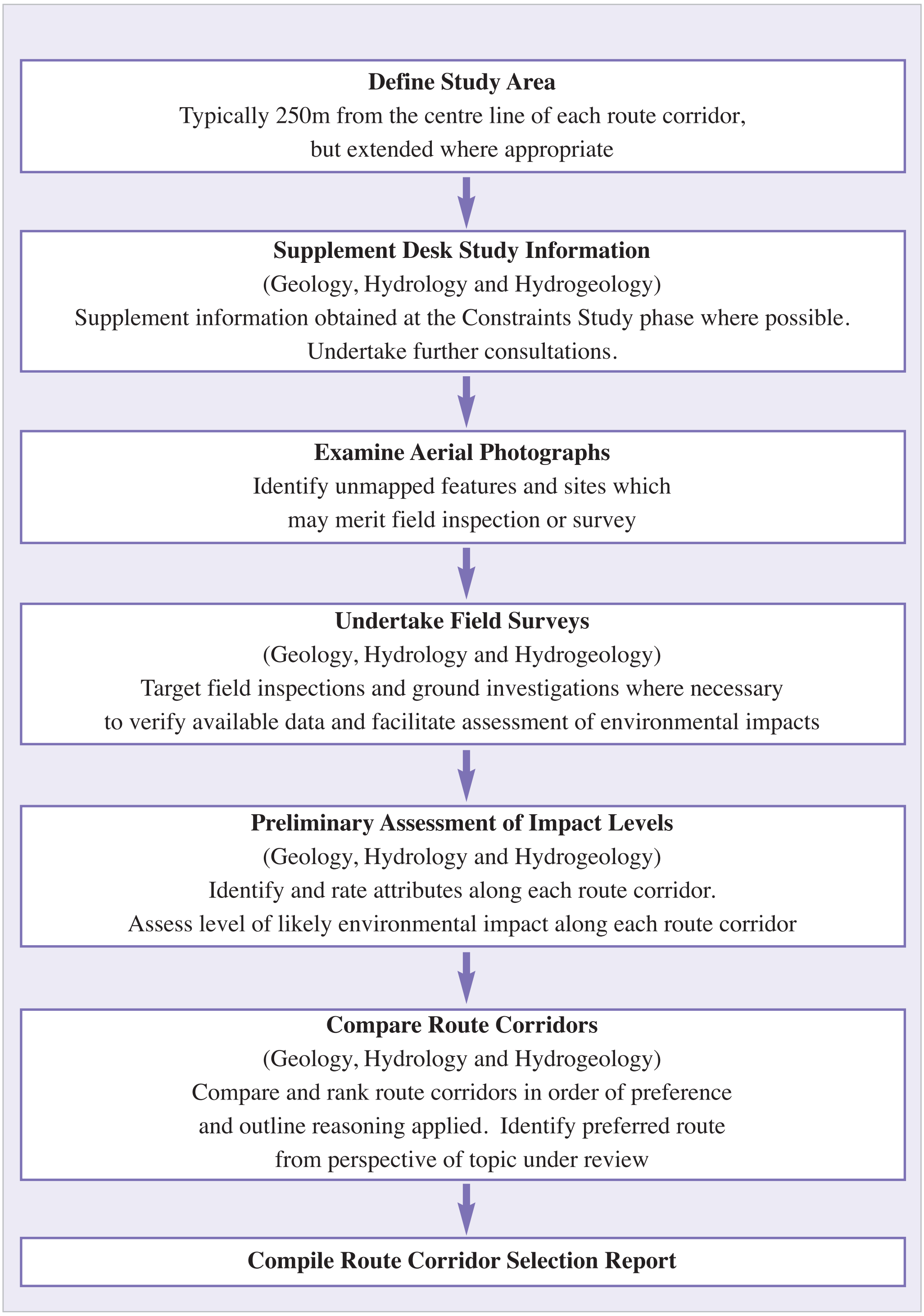

Figure 4-3: *Flowchart showing Phase 3 Route Corridor Selection Study*

Box 4.1: CRITERIA FOR RATING SITE ATTRIBUTES - Estimation of Importance of Soil and Geology Attributes

Importance	Criteria	Typical Examples
Very High	Attribute has a high quality, significance or value on a regional or national scale Degree or extent of soil contamination is significant on a national or regional scale Volume of peat and/or soft organic soil underlying route is significant on a national or regional scale*	Geological feature rare on a regional or national scale (NHA) Large existing quarry or pit Proven economically extractable mineral resource
High	Attribute has a high quality, significance or value on a local scale Degree or extent of soil contamination is significant on a local scale Volume of peat and/or soft organic soil underlying route is significant on a local scale*	Contaminated soil on site with previous heavy industrial usage Large recent landfill site for mixed wastes Geological feature of high value on a local scale (County Geological Site) Well drained and/or highly fertility soils Moderately sized existing quarry or pit Marginally economic extractable mineral resource
Medium	Attribute has a medium quality, significance or value on a local scale Degree or extent of soil contamination is moderate on a local scale Volume of peat and/or soft organic soil underlying route is moderate on a local scale*	Contaminated soil on site with previous light industrial usage Small recent landfill site for mixed wastes Moderately drained and/or moderate fertility soils Small existing quarry or pit Sub-economic extractable mineral resource
Low	Attribute has a low quality, significance or value on a local scale Degree or extent of soil contamination is minor on a local scale Volume of peat and/or soft organic soil underlying route is small on a local scale*	Large historical and/or recent site for construction and demolition wastes Small historical and/or recent landfill site for construction and demolition wastes Poorly drained and/or low fertility soils Uneconomically extractable mineral resource

* *relative to the total volume of inert soil disposed of and/or recovered*

Box 4.2: CRITERIA FOR RATING SITE ATTRIBUTES - Estimation of Importance of Hydrology Attributes

Importance	Criteria	Typical Examples
Extremely High	Attribute has a high quality or value on an international scale	River, wetland or surface water body ecosystem protected by EU legislation e.g. 'European sites' designated under the Habitats Regulations or 'Salmonid waters' designated pursuant to the European Communities (Quality of Salmonid Waters) Regulations, 1988.
Very High	Attribute has a high quality or value on a regional or national scale	River, wetland or surface water body ecosystem protected by national legislation – NHA status Regionally important potable water source supplying >2500 homes Quality Class A (Biotic Index Q4, Q5) Flood plain protecting more than 50 residential or commercial properties from flooding Nationally important amenity site for wide range of leisure activities
High	Attribute has a high quality or value on a local scale	Salmon fishery Locally important potable water source supplying >1000 homes Quality Class B (Biotic Index Q3-4) Flood plain protecting between 5 and 50 residential or commercial properties from flooding Locally important amenity site for wide range of leisure activities
Medium	Attribute has a medium quality or value on a local scale	Coarse fishery Local potable water source supplying >50 homes Quality Class C (Biotic Index Q3, Q2-3) Flood plain protecting between 1 and 5 residential or commercial properties from flooding
Low	Attribute has a low quality or value on a local scale	Locally important amenity site for small range of leisure activities Local potable water source supplying <50 homes Quality Class D (Biotic Index Q2, Q1) Flood plain protecting 1 residential or commercial property from flooding Amenity site used by small numbers of local people

Box 4.3: CRITERIA FOR RATING SITE ATTRIBUTES - Estimation of Importance of Hydrogeology Attributes

Importance	Criteria	Typical Examples
Extremely High	Attribute has a high quality or value on an international scale	Groundwater supports river, wetland or surface water body ecosystem protected by EU legislation e.g. SAC or SPA status
Very High	Attribute has a high quality or value on a regional or national scale	Regionally Important Aquifer with multiple wellfields Groundwater supports river, wetland or surface water body ecosystem protected by national legislation – NHA status Regionally important potable water source supplying >2500 homes Inner source protection area for regionally important water source
High	Attribute has a high quality or value on a local scale	Regionally Important Aquifer Groundwater provides large proportion of baseflow to local rivers Locally important potable water source supplying >1000 homes Outer source protection area for regionally important water source Inner source protection area for locally important water source
Medium	Attribute has a medium quality or value on a local scale	Locally Important Aquifer Potable water source supplying >50 homes Outer source protection area for locally important water source
Low	Attribute has a low quality or value on a local scale	Poor Bedrock Aquifer Potable water source supplying <50 homes

Box 4.4: CRITERIA FOR RATING IMPACT SIGNIFICANCE AT ROUTE SELECTION STAGE - Rating of Significant Environmental Impacts at Route Selection Stage

Impact Level	Attribute Importance				
	Extremely High **	Very High	High	Medium	Low
Profound	Any permanent impact on attribute	Permanent impact on significant proportion of attribute			
Significant	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute	Permanent impact on significant proportion of attribute		
Moderate	Temporary impact on small proportion of attribute	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute	Permanent impact on significant proportion of attribute	
Slight		Temporary impact on small proportion of attribute	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute	Permanent impact on significant proportion of attribute
Imperceptible			Temporary impact on small proportion of attribute	Temporary impact on significant proportion of attribute	Permanent impact on small proportion of attribute

** ***In rating impacts on an 'European site' account must be taken of Article 6(3) and 6(4) of the Habitats Directive*** *(Council Directive 92/43/EEC). Also see guidance contained within Guidelines for Assessment of Ecological Impacts of National Road Schemes (Rev 2, National Roads Authority, 2008)*

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CHAPTER 5

ENVIRONMENTAL IMPACT STATEMENT

5 ENVIRONMENTAL IMPACT STATEMENT

5.1 Objective

The objective in preparing the Soil and Geology, Hydrology and Hydrogeology sections of the Environmental Impact Statement (EIS) is to identify and quantify any significant impacts on the existing soil and water environments that are likely to arise as a result of the construction and operation of the preferred route option.

The EIS should be prepared in accordance with the EPA publication, 'Guidelines on the Information to be Contained in Environmental Impact Statements' (2002) and the NRA publication 'Environmental Impact Assessment of National Road Schemes – A Practical Guide' (Rev 1, NRA, 2008).

5.2 Approach

In order to identify and quantify the impact of the construction and operation of the preferred route option, it is first necessary to undertake a detailed study of the existing (baseline) geological, hydrological and hydrogeological environments (the 'receiving' environment) along the route. This will require collation and evaluation of available regional and local information and more site-specific data obtained from route walkover surveys, ground investigations, hydrogeological characterisation studies and surface water / groundwater monitoring and testing programmes.

The study area for detailed Environmental Impact Assessment (EIA) purposes should generally extend 250m beyond the landtake boundary for the preferred route and should be extended where the proposed road footprint lies outside this area, for example along link roads and/or re-aligned side roads. In such instances, the study area should also extend a similar distance (250m beyond the landtake boundary). Where appropriate, the study area should be extended to include nearby rock outcrops or exposures in road or railway cuttings, watercourses, certain wells and springs or other hydrogeological features. Professional judgement must also be exercised in assessing whether the study area needs to be extended to take account of potentially significant impacts which could arise a greater distance away (e.g. at groundwater dependent SAC / NHA sites which could be hydraulically connected over an extended distance to groundwater in a proposed road cutting).

Having obtained the necessary site-specific information, a description and evaluation of the existing soil and water environment is prepared. Thereafter, having defined the extent and form of the proposed road scheme, an assessment is made of its likely significant impacts on the soil and water environments and mitigation measures are identified to mitigate any significant adverse impacts.

Ideally all data acquired during the ground investigation and previous studies should be compiled and managed in digital format on a Geographical Information System (GIS) database and geotechnical database (AGS format).

5.3 Scoping

At the outset of the EIA process for preliminary road design, scoping should be undertaken to identify the likely significant impacts affecting the soil and water environments that need to be addressed by the EIS. The initial scoping for EIA should have regard to the information obtained at Constraints Study and Route Corridor Selection stages and should identify the location and sensitivity of soil and water receptors, the likely severity of impacts on them and how it is proposed to evaluate them during the EIA process.

Early consultation should be undertaken with relevant statutory consultees as part of the scoping process in order to:

(i) advise them about the proposed road scheme and potential environmental impacts on the soil and/or water environment;

(ii) identify any additional impacts that require attention in the EIS;

(iii) identify issues to be addressed in the planning and execution of walkover surveys, ground investigations, surface water or groundwater monitoring and soil / water testing;

(iv) obtain their views or recommendations regarding possible mitigation measures for potential impacts identified as 'likely' and 'significant'.

Views and suggestions submitted by statutory consultees should be incorporated into the scoping report.

During the scoping process it is important for geological, hydrological and hydrogeological consultants to liaise with each other as well as with the engineering design team and other environmental consultants. Discussions between consultants should focus on aspects where interactions are likely to arise such as agriculture, air quality, archaeology, ecology, landscape, noise and vibration.

The scoping report should be subject to continuous review as preliminary design of the road scheme proceeds in order to ensure that the EIA adequately addresses modifications to the road scheme and any implications these may have for assessment of environmental impacts.

5.4 Environmental Impact Assessment – General

The methodology for undertaking the EIA process is discussed in general terms below. More detailed guidance is provided in the NRA publication '*Environmental impact Assessment of National Road Schemes – A Practical Guide'* (Rev 1, NRA, 2008). Specific aspects relating to geology, hydrology and hydrogeology are discussed below, in Sections 5.5, 5.6, and 5.7.

In undertaking EIA, it is imperative that geological, hydrological and hydrogeological consultants liaise closely at all times with the engineering design team in order to ensure that:

(i) their requirements are adequately addressed in planning, scoping and executing the ground investigation;

(ii) they have access to the latest, most detailed and accurate topographical survey data along and in the immediate vicinity of the route;

(iii) their impact assessments identify and address all relevant aspects of the road scheme, including the proposed horizontal and vertical alignment, length and depth of cuttings, length and height of embankments, bridge structures, river culverts or crossings, drainage, attenuation ponds, soakaways and major utility diversions, and

(iv) the proposed mitigation measures are practicable and are incorporated into the overall design of the road scheme.

On national road schemes where EIS sections on soils and geology, hydrology and hydrogeology are prepared by separate consultants, particular efforts should be made to ensure consistency between them in the presentation of baseline information, assessments and recommendations.

5.4.1 Step 1: Baseline Data Collection

At the outset of the EIA for each topic, all data acquired at Constraints Study and Route Corridor Selection phases should be reviewed and collated. Any additional information which may be relevant should also be sought at this stage. Details of the preliminary road design and topographical mapping should be obtained from the engineering design team.

Baseline studies at EIA stage should be scoped and planned on the basis of available information on the geological, hydrological or hydrogeological environment and the preliminary design of the proposed road scheme. These studies will typically comprise some or all of the following:

- walkover surveys and geological field mapping;
- inspection of impacted sites, features and attributes;
- ground investigation contract(s), to include boreholes, rotary drillholes, trial pits, geophysical surveys, dynamic probes, cone penetration testing, in-situ testing of subsoils and groundwater permeability, monitoring of groundwater levels, laboratory testing and reporting in paper and digital format;
- well surveys;
- surface water monitoring (flows and levels), and
- surface and groundwater quality testing.

In planning and scoping these surveys, it is critical to ensure that they are:

- sufficient to characterise and evaluate the receiving environment;
- sufficient to identify and assess the impacts on the environment, and
- focused on those impacts which are both likely and significant.

For each of the three topics, the description of the existing environment in the EIS should initially address its context, having regard to the regional data presented in the Constraints Study and Route Corridor Selection Reports. Thereafter more detailed, site-specific information obtained from surveys, inspections, ground investigation, monitoring and testing should be used to make an evaluation of the local environment along the proposed road scheme taking account of its:

- character;
- significance, and
- sensitivity.

The natural and built landscape is continually changing and evolving. The description of the receiving environment should, therefore, also identify any trends or evidence of change impacting on it (changes in agricultural use, increased exploitation of natural resources, etc.)

5.4.2 Step 2 : Identify and Categorise the Impacts

Having completed the baseline studies, the available data can be used to identify and categorise all potential impacts likely to affect the geological, hydrological or hydrogeological environment as a result of the construction and operation of the proposed road scheme.

The assessment of the potential impacts of the proposed road scheme should involve a description / assessment of the impacts that are planned to take place, or can be reasonably foreseen. Impacts may be categorised as one of three types:

- **Direct Impact** where the existing geological, hydrological or hydrogeological environment along or in close proximity to the the route corridor is altered, in whole or in part, as a consequence of road construction and/or operation.
- **Indirect Impact** where the geological, hydrological or hydrogeological environment beyond the proposed route corridors is altered by activities related to road construction and/or operation.
- **No Predicted Impact** – where the proposed route corridor has neither a negative nor a positive impact on the geological, hydrological or hydrogeological environment.

The magnitude of impacts should be defined in accordance with the criteria provided in the EPA publication *Guidelines on the Information to be Contained in Environmental Impact Statements* (2002), outlined in Table 5.1: Impact Assessment Criteria::

Magnitude of Impact	Description
Imperceptible	An impact capable of measurement but without noticeable consequences
Slight	An impact that alters the character of the environment without affecting its sensitivities
Moderate	An impact that alters the character of the environment in a manner that is consistent with existing or emerging trends
Significant	An impact, which by its character, magnitude, duration or intensity alters a sensitive aspect of the environment.
Profound	An impact which obliterates all previous sensitive characteristics

Table 5.1: *Impact Assessment Criteria*

It should be recognised that impacts associated with national road schemes are not necessarily always negative and that positive impacts are sometimes possible (e.g. enhancement of geological exposures, reduction in serious pollution risk to surface waters). Impacts should, therefore, be identified as **positive**, **neutral** or **negative**.

Impacts may be described by reference to clearly defined criteria such as:

- the amount or intensity by which the character of the environment will change;
- the spatial extent of the impact, and
- the perceptibility, social implications or scientific significance of change.

Recognising that EIA is a predictive process and that a degree of uncertainty may attach to the assessments being made, those preparing the reports should indicate the degree of confidence or certainty attaching to their assessments using terms such as *certain* or *likely*. No consideration should be given to impacts which may be rated as *possible* or *unlikely*.

The duration of impacts should also be identified. Impacts may be:

- **temporary** (construction-related and lasting less than one year)
- **short-term** (lasting one to 7 years)
- **medium-term** (lasting between 7 to 15 years)
- **long-term** (lasting 15 to 60 years)
- **permanent** (lasting over 60 years)

The type or nature of the impacts may be more fully described with respect to the following criteria

- **Cumulative Impact**, where the combination of many minor impacts creates one, larger, more significant impact.

- **Potential Impact** which is the impact of the proposed development before mitigation measures are fully established.

- **Worst-case Impact** which is the impact of the proposed development should mitigation measures substantially fail to fulfil their intended function.

- **Residual Impact** which is the final or designed impact which results after proposed mitigation measures have fully established.

Source: Environmental Protection Agency, 2003. *Advice Notes on Current Practice (in the Preparation of Environmental Impact Statements)*. EPA Wexford.

To place the predicted impacts into some context, it is often helpful to identify the '**do-nothing**' **impact.** This involves identifying existing trends in the environment (particularly planning, land-use and development pressures) and making a qualitative assessment of likely future implications for soils, geology, surface water and/or groundwater. In presenting the 'do-nothing' scenario, it should be assumed that the existing regulatory regime and/or any environmental management programmes continue into the future.

5.4.3 Step 3: Rate the Impacts

The rating of potential environmental impacts of national road schemes on geological, hydrological or hydrogeological environments should be assessed by:

(i) classifying the importance of the relevant attributes, and

(ii) quantifying the likely magnitude of any impact on these attributes.

The importance of geological, hydrological or hydrogeological attributes should be assessed on the basis of their quality, extent (scale) and rarity. Typical criteria to be applied in assessing the importance of geological, hydrological and hydrogeological attributes are presented in Boxes 4-1 and 4-2, 4-3.

Typical criteria to be applied in quantifying the magnitude of potential environmental impacts on identified geological, hydrological and hydrogeological attributes are presented in Boxes 5-1 , 5.2 and 5-3. The assessment techniques used to quantify the likely magnitude of environmental risks and impacts are discussed in more detail for each specific topic in Sections 5.5, 5.6 and 5.7.

The importance of an attribute and the magnitude of the impact are both important in rating potential environmental impacts. For example, a small adverse impact on a very important attribute could represent a moderate to significant adverse impact, e.g. sterilisation of small proportion of future reserves at a large quarry or potential low risk of pollution to a regionally important aquifer.

For EIA purposes, therefore, the rating of potential environmental impacts on geological, hydrological and hydrogeological environments should be based on the matrix presented in Box 5-4 which takes account of both the importance of an attribute and the magnitude of the potential environmental impact(s) of the road scheme on it.

5.4.4 Step 4 : Mitigation Measures

Mitigation measures are those measures which are identified and developed in the course of the preliminary road design phase to avoid, reduce and, if possible, remedy any negative impacts on the environment. The identification and development of mitigation measures is an integral part of the preliminary road design process and it is important that environmental consultants interface with the engineering design team when developing solutions and/or identifying landtake requirements

There are three established strategies for impact mitigation: - avoidance, reduction and remedy. Avoidance is the most effective mitigation measure and is most easily achieved at the Constraints Study and/or Route Corridor Selection stage. Mitigation may have involved significantly amending the horizontal alignment of the preferred route to ensure it does not run across or in close proximity to a sensitive site or attribute. The EIS should document such measures. If it is not possible to avoid the potential impact entirely and a likely significant impact remains, consideration should be given to locally modifying the proposed road alignment to:

- reduce (minimise) the extent of the impact, or
- reduce (minimise) the exposure (of people, flora and fauna) to the impact.

When modifying the proposed road alignment, due regard must be given to the potential negative knock-on implications for other environmental receptors. Impact reduction measures are typically implemented during the preliminary engineering design stage.

If it is not possible to reduce the impact by modifying the road alignment, then specific engineering and/or construction solutions need to be developed and incorporated into the road scheme to deal with unavoidable adverse significant impacts which are likely to arise during the construction and/or operation of the road scheme. Remedial measures are typically implemented during the construction stage.

Following agreement on the extent of mitigation measures to be incorporated into the road scheme, the environmental impact statement should quantify the ‘residual’ environmental impact of the scheme on sensitive sites or attributes.

In general project-specific post-construction monitoring is normally carried out in situations where substantial or innovative mitigation, compensation or enhancement measures are undertaken for protected flora and fauna as part of the requirements of a derogation licence issued by the National Parks and Wildlife Service (NPWS) of the Department of the Environment, Heritage, and Local Government.

Post-construction monitoring for national road schemes may be undertaken for a specified time period following the road opening. Unless exceptional site specific circumstances apply post-construction monitoring should generally only be considered in the vicinity of abstraction points or wells for major public water supply schemes, and only be undertaken for a period of up to 12 months.

Post construction monitoring forms an integral part of the NRA's environmental integration model. Currently post construction monitoring, covering a range of environmental matters, is carried out under the Authority's Research programme.

5.5 Environmental Impact Assessment – Soil and Geology

5.5.1 Description of the Existing Geological Environment

The study of the receiving environment for the Soil and Geology section of the EIS supplements the information obtained during the previous Constraints and the Route Corridor Selection Studies using:

- relevant published or pre-existing information;
- feedback from consultations with statutory consultees, interested organisations and affected third parties;
- a walkover survey of the entire road scheme;
- results of geophysical surveys undertaken along the proposed road alignment;
- findings of ground investigations (boreholes, rotary drillholes, trial pits and probes) along the proposed road alignment, and
- in-situ and laboratory test data.

At the outset of the EIA process, the geological information obtained at Constraints Study and Route Corridor Selection phases should be supplemented with information from other sources wherever possible. These sources may include:

- Open File (Exploration) Data held by the Geological Survey of Ireland or the Exploration and Mining Division of the Department of Communications, Energy and Natural Resources (refer to Section 2.1.5 of these Guidelines);
- National Soil Survey of Ireland – selected counties only (An Foras Talúntais);
- Speleological Union of Ireland (caving);
- Academic / Professional Geological Publications and Seminar Proceedings, and
- Reports on previous Ground Investigations close to the proposed alignment.

A comprehensive walkover survey should also be undertaken along the full length of the road scheme by the consultant preparing the Soil and Geology section of the EIS in order to assist in the identification and assessment of the environmental impact of the scheme on the geological environment and on features of geological interest. The quality of information obtained from the walkover survey may be considerably enhanced by undertaking some preparatory work in advance to identify specific sites and features of interest from existing information sources and aerial photographs.

When undertaking geological studies at Environmental Impact Assessment (EIA) stage, it is recommended that the study area should extend 250m beyond the landtake boundary for the proposed route mainline. This area may need to be increased where the proposed road footprint is extended for example, to make provision for link roads, re-aligned side roads, accommodation tracks or re-aligned watercourses or other related infrastructure. Where appropriate, the study area could be extended to include nearby rock outcrops or exposures in road or railway cuttings. Notwithstanding this, professional judgement must be applied in assessing whether the study area needs to be extended to take account of likely significant impacts which could arise some distance from the road (e.g. where local pits or quarries which may have a proportion of future aggregate resource sterilised as a result of the proposed road scheme).

Figure 5-1: *Exposure of horizontally bedded calcareous shale at Streedagh, Co. Sligo*

During the walkover survey, the opportunity should be taken, if appropriate, to speak to landowners or people living locally about events and changes which may have occurred in the vicinity of the proposed route in recent memory. Relevant issues might include infilling of former pits, quarries or closed depressions, land reclamation projects, arterial drainage schemes, etc.

At the preliminary design / EIA stage, the principal source of site-specific information for the Soils and Geology section is obtained by the ground investigation contract. As ground investigation contracts are conventionally scoped, procured and managed by geotechnical engineers on the project design team, it is essential that the specialist consultant preparing the Soil and Geology section of the EIS liaises closely with the engineering design team responsible for planning and scoping the ground investigation. It is the responsibility of the EIA Project Manager to ensure that the ground investigation provides sufficient information for EIA purposes.

In planning and scoping the ground investigation for EIA purposes, specific regard should be had to the following issues:

- suitability of geological materials excavated at cut sections for re-use in constructing earth structures (embankments);

- investigation of previously identified areas of (localised) soft or poorly drained ground;
- investigation of previously identified areas of Made Ground along, or in close proximity to, the route for potential contamination. Should any evidence of buried non-inert wastes or potential contamination by hydrocarbons or other industrial compounds be identified by boreholes or trial pits, soil samples should be taken for soil quality testing;
- identification of buried geological features in a karst environment (eg. infilled or open cavities);
- potential for, and implications of, slope instability on existing structures or infrastructure nearby;
- likely impact of road construction and operation on geological heritage sites (if any);
- likely impact on mineral or aggregate resources (either currently being extracted or potentially developable in future);
- potential requirement for blasting in cuttings and impacts of same on existing structures or infrastructure nearby (noise and vibration);
- potential requirement for pile driving at bridge structures and impacts of same on existing structures or infrastructure nearby (noise and vibration), and
- potential requirements for tunnel construction and impacts of same on structures or infrastructure nearby (noise and vibration, settlement and instability).

In sampling potentially contaminated soil and/or subsoil, regard should be had to guidance provided in *BS10175 Investigation of Potentially Contaminated Sites – Code of Practice* and particular precautions must be taken to avoid cross contamination between samples. Testing of potentially contaminated soil should determine the concentration of contaminants in both the solid and liquid phase. Testing for soil in its solid phase should include all contaminants for which Soil Guideline Values have been developed for the UK Environment Agency's Contaminated Land Exposure Assessment (CLEA) Model. Testing of leachate generated from soil samples should include all contaminants identified by *Council Decision 2003/33 establishing criteria and procedures for the acceptance of waste at landfills*. Further advice on issues related to contaminated land is given in *Guidelines for the Management of Waste from National Road Construction Projects* (NRA, 2008).

In planning and scoping the ground investigation, consideration should be given to targeted use of non-invasive geophysical survey techniques, particularly along road cuttings and in karst limestone areas. Guidance on the selection of appropriate geophysical techniques may be sought from the CIRIA publication *Geophysics in Engineering Investigations* (CIRIA C562) or from a geophysical contractor.

Drilling and excavation for the purposes of examining the nature and depth of the subsoil is generally classified as exempted development for planning purposes. However, drilling and excavation within designated or proposed Special Areas of Conservation (SACs) requires the

prior consent of the Minister for Environment, Heritage and Local Government and/or the National Parks and Wildlife Service. Drilling and excavation along the foreshore requires a public notice to be published and Minister for Energy, Communications and Natural Resources to be notified at least four weeks in advance of commencing the works.

An outline of some conventional investigative techniques used to obtain the information outlined above is provided in Table 5.2. Note that this list is not intended to be exhaustive and other investigative techniques may also be considered:

Geological Parameter	Method of Determination
Depth of subsoil / depth to bedrock	Trial pits Cable percussion boreholes Percussive drillholes
Rock type, weathering, structure	Rotary core drillholes
Soil re-useability	Soil compaction, MCV and CBR tests
Soil contamination	Soil quality tests (as per CLEA Soil Guideline Values) Soil leachate tests (as per Council Decision 2003/33 criteria)
Buried cavities (in karst)	Geophysical surveys (microgravity, ground penetrating radar)
Soil strength / stability	Standard penetration tests (SPT) Undrained shear strength tests Effective stress strength tests
Aggregate resource	PSD analysis (of granular soil) Petrographic analysis (of rock) Rock aggregate testing
Rock excavatability	Rock strength tests Geophysical surveys (seismic refraction)
Soil compressibility (settlement)	Oedometer tests

Table 5.2: *Investigation Techniques for Assessment of Geological Impacts*

Since much of the focus of the ground investigation is on the engineering design of the route, detailed advice on the scoping and planning of the ground investigation is considered to be beyond the scope of these guidance notes. Guidance on scoping and planning of ground investigations is provided in Part 1 of the *Specification and Related Documentation for Ground Investigation* published by the Institution of Engineers of Ireland (2006).

The consultant preparing the Soils and Geology section of the EIS should liaise closely with geotechnical engineers on the project design team to ensure that their report accurately reflects the engineering characteristics (strength, deformability, permeability, re-usability) of the in-situ / excavated soil or rock and is consistent with findings presented in the Geotechnical Interpretative Report.

5.5.2 Geological Impact Assessment

The assessment of the geological impacts of a proposed road scheme should be based on the analysis and interpretation of data acquired during the Constraints Study and Route Corridor Selection phases and by ground investigations undertaken for the purpose of the EIA process. The prediction of impacts arising from a national road development must be based on transparent and objective (scientifically demonstrable) criteria.

In undertaking the detailed assessment of the likely significant impacts of the road scheme on soils and geology, regard should be had to the following specific topics:

- Soils (range of agricultural uses, fertility and drainage characteristics);
- Requirements for treatment and/or handling of soft, unstable or contaminated soils, subsoils or other geological materials;
- Requirements for excavation, disposal and/or recovery of soils, subsoils or other geological materials which may be unsuitable for re-use in construction of earth structures or present a risk to human health and/or the environment;
- Environmental impact of engineering works on, in or over karst features (buried open / infilled cavities, slope and pavement stability);
- Economic Geology (mines, pits and quarries), and
- Geological Heritage.

The scheme for categorising, assessing and rating the significance of geological impacts should be based on that presented in Section 5.4 and Box 4-1 and 5-1 of these guidelines.

The degree of contamination of soil samples tested during the ground investigation (if any) should be assessed using the Soil Guideline Values developed using the UK Environment Agency's Contaminated Land Exposure Assessment (CLEA) Model. **Soil Guideline Values have superseded earlier limit values for the assessment of risks to human health set by the Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL).** If significant levels of soil contamination are encountered, the engineering design team and relevant authorities must be notified at the earliest opportunity as this may necessitate a review of the preferred route corridor.

Requirements for off-site disposal and/or recovery of geological materials which may be unsuitable for re-use in construction of earth structures should have regard to *Council Decision*

2003/33 establishing criteria and procedures for the acceptance of waste at landfills and *Guidelines for the Management of Waste from National Road Construction Projects* (NRA, 2008).

Figure 5-2: *Closed depressions in the landscape are suggestive of underlying karstified limestone*

The impact of the proposed road scheme on established pits and quarries should have regard to the existing scale and direction of extraction activities, established methods of working, range of value added activities undertaken on site and potential sterilisation of reserves (which arise indirectly through restrictions on future excavation and/or blasting).

In assessing the scale of the impact of the proposed road scheme on a designated geological heritage site (NHA), it is important to bear in mind that management issues for geological heritage sites can differ significantly from ecological sites, and in some cases road development may actually facilitate enhanced geological understanding of a site by exposing more rock sections in (say) a new road cutting. Paradoxically, many geological heritage sites are only known about because some excavation or development has occurred.

Some geological heritage sites will be simply representative of particular regional or stratigraphical geology, as for example, a working limestone quarry. They may be the only (or the best) place to see particular types of rock. In such circumstances, a nearby alternative such as a new road cutting, may in fact constitute a positive impact with respect to geological heritage. However, where a site has a discrete interest that is irreplaceable if destroyed, any change is likely to constitute a major negative impact.

In undertaking impact assessment, the relevant consultant(s) should be consulted on:

- impacts on soils (agricultural value and fertility);
- impacts on mining heritage areas;
- the archaeological importance of any of sediments in cave systems;

- risks to water quality presented by surface water run-off or excavation of contaminated sites, and
- the visual impacts of rock cuts.

5.5.3 *Geological Mitigation Measures*

For the Soil and Geology topic, the following mitigation measures may be considered and incorporated, as appropriate, into the road scheme at preliminary design stage:

- locally re-align the horizontal alignment (e.g. to minimise length over soft or contaminated ground);
- locally re-align the vertical alignment (e.g. to minimise volume of geological materials requiring off-site disposal or recovery);
- provide for excavation and off-site disposal and/or recovery of unacceptable and/or contaminated soils in accordance with the Waste Management Acts, 1996-2008, and associated regulations and guidance provided in the NRA's *Guidelines for the Management of Waste from National Road Construction Projects* (National Roads Authority, 2008);
- provide for in-situ remediation of contaminated soils;
- engineering design solutions / contingencies (e.g. use of gabions, soil nailing, structural retention systems to deal with ground instability), and
- removal or protection of geological resource during construction period.

The Agricultural Consultant should advise about mitigation measures to minimise potential impacts on fertile, productive soils and, where required, the Archaeological Consultant should advise on mitigation measures to protect mining heritage or any archaeological resource in cave systems.

Figure 5-3: *Caves are of geological interest not only on account of the remarkable natural formations within them (such as the stalactites shown above) but also because sediments within the cave may be many millions of years old (in contrast to the majority of soils at the surface) and may host archaeological remains.*

Mitigation measures for geological heritage sites will generally need to be individually tailored for each affected site. Usually the site context is a critical part of the scientific interest, but for very restricted sites (e.g. fossils or minerals), consideration could be given to removal to a new site or to a museum.

New road cuttings may have a positive impact for geology provided the exposed face is not obscured by topsoil or new planting. Where such impacts are identified, it will be necessary to liaise with the Landscape Consultant to agree the appropriate form of landscape treatment at such cuttings. Regard should also be had to the NRA *Guide to Landscape Treatments for National Road Schemes in Ireland*.

Figure 5-4: *Example of Limestone pavement Co. Galway*

In order to expand the understanding of the Irish geological environment, specific consideration should be given to the value of recording geological data revealed in roadside cuttings during construction using the Geological Survey of Ireland's Temporary Exposures Form. At a minimum, site-based construction personnel should record the nature and depth of any soil cover and the rock type and corresponding Irish National Grid (ING) co-ordinates. Ideally a site based geological or engineering professional should also record additional information on rock dip angle and direction, structure, bedding, folding, weathering, etc.

5.5.4 Contents of Geological EIS Report

A detailed description of the bedrock geology and subsoil deposits along the proposed road alignment should be prepared for the Environmental Impact Statement report. The report should present information on the topics outlined below:

- Introduction;
- Methodology – to include a brief statement of how the EIS was prepared, with details of all data sources, consultations undertaken, field surveys, findings from the ground investigation, limitations in methodology and gaps in data;
- Regional Overview of Agricultural Soils, Subsoil Deposits and Solid Geology within original study area;
- Description of Soils, Subsoils and Solid Geology along the proposed route, identifying geological issues of importance / significance. Cross reference with the Agriculture section of the EIS as appropriate;
- Description of historical land use along and in vicinity of the proposed route. Cross reference the Archaeological section of the EIS as appropriate;
- Description of karst and karst features in limestone areas along and in vicinity of the proposed route;
- Description and identification of soft, unstable, contaminated land and geohazards along and in vicinity of the proposed route;
- Description of mineral / aggregate resources along and in the vicinity of the proposed route;
- Description of geological heritage along and in the vicinity of the proposed route. Cross reference any mining heritage or archaeological aspects with the Archaeological section of EIS as appropriate;
- Impact Assessment of the proposed route– to identify all likely significant potential impacts affecting soils and geology along and in the vicinity of the proposed route. Cross reference the Agricultural, Archaeological and Landscape sections of the EIS as appropriate;

- Mitigation Measures required and assessment of residual impacts. Cross reference the Agricultural, Archaeological and Landscape sections of the EIS as appropriate;
- References / List of Information Sources;
- Glossary, and
- Figures / Maps.

Maps accompanying the Soils and Geology section of the Environmental Impact Statement should include:

- a Bedrock Geology Map (identifying structural bedrock features, depth to bedrock, karst areas / features and mineral / aggregate resources, where present);
- a Depth to Bedrock Map showing the depth / elevation of bedrock along the road alignment;
- a Subsoil Map (identifying soft ground deposits, Made Ground, contaminated ground and aggregate resource areas);
- a Soils Map; and
- schematic Geological Cross-Sections showing factual ground investigation data along the centre-line of the route and along all re-aligned side roads and link roads.

All geological features previously identified during the constraints and route corridor selection studies should be clearly shown with any additional features recorded in the course of the detailed walkover survey added.

All geophysical survey lines and ground investigation locations should be shown on the geological cross-sections. No geological or geotechnical interpretation on soil profiles between exploratory locations should be indicated on geological cross-sections. Exaggeration of vertical and horizontal scales on cross-sections should typically be between 1v:5h and 1v:10h.

5.6 Environmental Impact Assessment - Hydrology

5.6.1 Description of the Existing Hydrological Environment

The baseline EIS study builds on the information obtained during the previous Constraints Study and the Route Corridor Selection Study and is prepared using:

- relevant published and pre-existing information;
- feedback from consultations with statutory consultees, interested organisations and affected third parties;
- detailed observations from a walkover survey of the entire route recording all watercourses, streams and rivers to be crossed by the proposed road alignment;
- information in respect of existing (or planned future) abstractions and discharges;
- results of surveys undertaken at the crossings along the proposed road alignment;
- flow records (hydrological data) from gauged rivers and larger streams;
- flooding records
- flow measurements taken at previously ungauged watercourses (at low and average flow) where it is proposed to discharge road run-off. Flow should ideally be measured twice, at seasonal high and low flow. Flow will typically be measured using a current meter;
- measurements made at the inflow and outflows of any wetlands in the vicinity of the proposed road alignment;
- results of water quality monitoring at rivers, streams and surface water bodies. Test parameters will vary depending on the relevant water quality standards (drinking, bathing, salmonid), they should typically include but not be limited to:
    - Temperature
    - pH value
    - Conductivity
    - Dissolved Oxygen
    - Biochemical Oxygen Demand
    - Ammoniacal Nitrogen
    - Suspended Solids
    - Nitrate
    - Orthophosphate

  - Total Hardness
  - Zinc (total)
  - Copper (dissolved)
  - Petroleum Hydrocarbons

- Water quality monitoring of lakes should also include:

  - Chlorophyll
  - Transparency

- results of water quality monitoring of any wetlands in the vicinity of proposed crossings (undertaken in association with biological surveys). Typical test parameters should be the same, but not limited to, those identified above; and

- detailed analysis and interpretation of the data collected.

At the outset of the EIA process, the hydrological information obtained at Constraints Study and Route Corridor Selection should be supplemented with information from other sources wherever possible. These sources may include:

- Climate Data from Met Éireann;

- Agroclimatic Atlas of Ireland (Collins and Cummins, AGMET, 1996);

- Hydrometric and Flood Data from the Office of Public Works, River Basin Management Projects, Environmental Protection Agency and Electricity Supply Board;

- Water Quality Data from River Basin Management Projects or Environmental Protection Agency;

- Drainage maps published by An Foras Talúntais, Teagasc, AGMET, and

- Reports previously published by An Foras Forbatha.

When undertaking hydrological studies at Environmental Impact Assessment (EIA) stage, it is recommended that the study area should extend 250m beyond the landtake boundary for the proposed route mainline. This area may need to be increased where the proposed road footprint is extended for example, to make provision for link roads, re-aligned side roads, accommodation tracks or re-aligned watercourses or other related infrastructure. Notwithstanding this, professional judgement must also be applied in assessing whether the study area needs to be extended to take account of potentially significant impacts which could arise a greater distance away (e.g. at downstream water dependent SAC / NHA sites).

At the outset of the EIA process, an inspection of stream and river crossings / realignments along the road scheme should also be undertaken by the Consultant preparing the hydrology section of the EIS. This survey is necessary to assist in the identification and assessment of the environmental impact of the scheme on the hydrological environment and on features of hydrological interest. Inspections should have specific regard to the stream or river channel to be crossed and both banks, the channel shape and stability, bed substrate and vegetation at each crossing points.

If appropriate, the opportunity can be taken in the course of the site walkover to speak to landowners or people living locally about events and surface water features in the vicinity of the proposed route in recent memory. Relevant issues might include recent flood events, arterial drainage schemes, location of springs etc.

Where desk-based studies, historical mapping and/or aerial photography indicate that river channels are unstable and shifting over time, the river channel should be visually inspected for a distance of 1.0 kilometre upstream and downstream of the proposed crossing points. A record should be made of their existing alignment, slope, bed characterisation and the presence of any meanders. If a stream or river has a tendency to meander, a record should be made of the stretches where the banks are being undercut and where deposition occurs. If meandering occurs upstream of a crossing point, the river may impact on the crossing. If meandering occurs downstream of the crossing point, the crossing may have an impact on the river channel.

Any flood plains crossed by the proposed road alignment should also be inspected to identify whether the river overtops its banks in floods. Where possible, the height of likely flood levels should be assessed on basis of visual evidence such as debris along river banks etc. An indication of the size of the stream or river during winter flow conditions (and water levels) may be obtained from local landowners, fishermen or scientists / engineers involved on River Basin Management Projects

The locations of any water abstractions and effluent discharges close to potential crossings along the proposed route should be identified and confirmed and details of the volumes of abstraction and discharge should be obtained where possible. The location of any control measures such as dams, weirs or locks should also be identified and confirmed.

Water quality monitoring should generally be undertaken upstream and downstream of all drainage outfalls for the proposed road scheme. Water quality monitoring should also be considered where the proposed road scheme crosses salmonid streams or streams containing protected species and their tributaries. Additional water quality monitoring may be undertaken at streams where the ecologist advises there could be significant impacts on sensitive ecological habitats. Water quality monitoring should be undertaken twice in each river or stream, ideally at seasonal high and low flow, possibly at the same time as biological surveys. To ensure surface water samples are of good quality, no disturbance of river bed sediments should occur during sampling.

It is essential that the specialist consultant liaises closely with the engineering design team responsible for planning and scoping the ground investigation. They should ensure that any geological or hydrogeological information required for EIA assessment and design of hydrological mitigation measures, including attenuation ponds or soakaways, is obtained as part of the ground investigation contract.

5.6.2 Hydrological Impact Assessment

The assessment of the hydrological impacts of a proposed road scheme should be based on the analysis and interpretation of data acquired during the Constraints Study and Route Corridor Selection phases and by hydrological investigations undertaken for EIA purposes. The prediction of impacts arising from a national road development must be based on transparent and objective (scientifically demonstrable) criteria.

The construction of a national road scheme is likely to affect the flood response of the catchment within which it is located. The increase in impervious area means that a greater proportion of the incident rainfall will appear in the drainage system as surface run-off. The provision of sealed pipes (e.g. in areas of extremely vulnerable karstified limestone) to convey run-off from the road to existing watercourses will result in larger (concentrated) volumes being discharged at point locations within a shorter duration.

Construction of road crossings (culverts / river underbridges) or discharges to watercourses can have the following types of impacts on water quality and fisheries:

- Direct removal of riverine and bankside habitat;
- Creation of barriers to fish movement;
- Short-term construction impacts;
- Pollution from road run-off;
- Pollution from accidental hazardous spillage, and
- Impacts on river geomorphology.

The scheme for categorising, assessing and rating the significance of hydrological impacts should be based on that presented in Section 5.4 and Box 4-2 and 5-2 of these guidelines.

Significant impacts on fisheries may occur at watercourse crossings if culvert or bridge construction involves complete or partial removal of the in-channel habitat or the loss of bankside habitat. The culverting, re-alignment or re-sectioning of river channels can create barriers to fish movement. This is especially the case if the new channel is too shallow or water flow through the new channel is too fast, the culvert opening is too narrow or there is a fall downstream of the culvert opening.

Re-sectioning or re-aligning river channels can also affect the geomorphological processes which control river habitats and can therefore have indirect impacts on water quality and fisheries upstream or downstream of the directly affected section of channel. In assessing the impact of changes in channel geometry and construction on fisheries, it is important to liaise with the consultants preparing the aquatic ecology section of the EIS.

Temporary impacts on surface waters will occur during road construction. Pollution from mobilised suspended solids (silt) is generally the prime concern, but accidental spillage of fuels, lubricants and hydraulic fluids from construction plant may also lead to incidents. The spillage of concrete is of particular concern to fisheries. Run-off after droughts, when flow in watercourses is low, may be more hazardous.

Contaminants in road run-off drainage can have long-term negative impacts on water quality. Most contaminants are derived from either wear and tear of vehicles' mechanical parts or from combustion of fuel and oil leaks. Degradation of the asphalt surface also contributes to contaminants in run-off. Monitoring programmes (studies) have shown a range of contaminants in surface water run-off from roads (metals, herbicide constituents, polycyclic aromatic hydrocarbons (PAHs) and other organic substances).

In general, the concentration of contaminants in surface water run-off from a road scheme increases with traffic density. The UK Highways Agency's Design Manual for Roads and Bridges (DMRB) suggests that '*pollution impacts on receiving waters appear to be restricted primarily to roads carrying more than 30,000 vehicles per day (AADT), although for roads carrying less than 15,000 vehicles per day the level of pollution associated with runoff to sensitive waters could be of concern*'. Simple and detailed methods for the assessment of pollution impacts from routine road run-off are presented in Methods A and B respectively in Annex 1 of HA216/06 (UK DMRB). In assessing the risk of pollution impacts from road run-off, due regard should be had to anticipated increases in rainfall intensity on account of future climate change. The findings of the recent EPA publication *'Impact Assessment of Highway Drainage on Surface Water Quality'* (Bruen *et al*, 2006) should also be considered. This report conducted detailed biological and physio-chemical analysis on streams, from different areas across Ireland, with discharges from national roads. The study examined the effects downstream of the discharge points and made a comparison with upstream values.

Consideration should be given to the risk of accidents which could give rise to hazardous spills. Formulae have been developed that allow the probability of a serious accident occurring leading to a pollution incident to be calculated, refer to Appendix B3 and Method D in Annex 1 of HA216/06 (UK DMRB). The return period for both serious accidents and resulting pollution incidents can be calculated for each drainage outfall along the proposed road. Assessment of return periods of both serious accidents and resulting pollution incidents should take account of anticipated increases in rainfall intensity as a result of future climate change.

Construction across floodplains can affect the nature and extent of the flood envelope in the area of construction and for some distance up and downstream. This could have a serious impact on property owners within or near the floodplain, who may become exposed to an increased risk of flooding. In areas where national road schemes cross an existing floodplain or area of flood risk, consideration should be given to use of flood prediction models to assess the existing and likely future flood risk. The requirement for, and complexity of, flood modelling should reflect the likely social and/or economic impact of increased and/or more frequent flooding were it to occur. Assessment methods should be based on methodologies similar to Methods E and F in Annex 1 of HA216/06 (UK DMRB).

Road construction may impact on the amenity value of a watercourse. Where a river, reservoir or canal is used for leisure activities, such as fishing or boating, these may be affected by the scheme. The road may interfere with the access to a facility or the enjoyment of an activity.

In undertaking impact assessment, the Ecological consultant should advise on impacts on aquatic habitats and the Consultant preparing the Material Assets section of the EIS should advise on impacts on water supplies or amenity value.

5.6.3 Hydrological Mitigation Measures

The impact of road construction on natural watercourses can be minimised by applying sound design principles and by following good work practices. For surface water, the following mitigation measures may be considered:

5.6.3.1 Construction Phase (short-term)

- minimisation of in-stream works and timing of such works so as to avoid seasonal fish runs and spawning periods;
- interception, channelling and/or discharge of surface water from sumps, excavations and exposed soil surfaces to silt traps or settlement lagoons;
- construction of silt traps, settlement lagoons / ponds, wetlands or hydrocarbon interceptors (either temporary or permanent) at sensitive outfalls at an early stage in the construction programme;
- construction of cut-off ditches to prevent surface water run-off from entering excavations;
- placing of granular materials over bare soil in the vicinity of watercourses in order to prevent erosion of fines and/or rutting by site traffic;
- storage of fuel, oils and chemicals on an impermeable base, away from drains and watercourses. Fuel storage areas should be bunded to provide adequate retention capacity in the event of a leak or spillage occurring;
- refuelling of plant and vehicles on impermeable surfaces, away from drains and watercourses;
- provision of spill kits at high risk and/or sensitive sites;
- installation of wheelwash and plant washing facilities having no overflow where effluents are retained pending treatment and disposal;
- implementation of measures to minimise waste and ensure correct handling, storage and disposal of waste (most notably wet concrete and asphalt); and
- specifying regular monitoring of surface waters during the construction period.

- Guidance on the treatment of aquatic ecology during the construction phase is provided in the NRA publication *Guidelines for the Crossing of Watercourses during the Construction of National Road Schemes*.

- Additional guidance on the protection of surface and groundwater during construction is given in the CIRIA publication *Control of water from linear construction projects. Technical guidance. Ciria C648*.

5.6.3.2 Operational Phase (long-term)

- construction of silt traps, sedimentation basins or hydrocarbon interceptors at sensitive outfalls;

- installation of systems of sedimentation or filtration of suspended solids with the parallel effect of removing contaminants (including certain heavy metals and hydrocarbons) associated with the suspended solids;

- ensuring drainage outfalls are served by suitably sized constructed wetlands or interceptor ponds where receiving waters are considered important from a fisheries standpoint or used as a water supply;

- fitting of spill containment measures at outfalls where it has been assessed that the annual risk of a serious pollution incident is greater than 1% (return period of less than 100 years) as determined using Method D in Annex 1 of HA216/06 (UK DMRB);

- attenuation of surface water run-off by holding ponds to reduce impact on stream flow;

- discharge of surface water run-off to groundwater using swales, french drains or soakaways;

- provision of granular drainage blankets (starter layers) at the base of earth embankments over sloping ground to minimise confinement of overland and/or near-surface flow on the upslope side of the embankment;

- provision of surface water collector drains parallel, and adjacent to, the toe of earth embankments;

- building a road across a floodplain can have a significant effect on flood levels, whereas building one alongside will be less. Providing compensatory flood storage can significantly mitigate the effect of a road scheme on the maximum flood level, and

- specifying regular monitoring of surface waters for a defined period after opening of the road scheme.

Further guidance on the treatment of aquatic ecology is provided in the NRA publication, *Guidelines for Assessment of Ecological Impacts of National Road Schemes*.

In formulating hydrological mitigation measures, regard should be had to the requirements of the Water Framework Directive and take account of the provisions of the Flooding Directive. In developing mitigation measures and refining the design of river and stream crossings, there should also be co-ordinated and ongoing consultation with the River Basin Management Projects, local authorities, Group Water Schemes, the Regional Fisheries Board and Office of Public Works as required.

The consultant preparing the aquatic ecology section of the EIS should advise on mitigation measures in respect of aquatic habitats. The consultant preparing the material assets section should be consulted on any mitigation measures to be implemented in respect of water supplies.

Figure 5-5: *Stream flow monitoring for M7/M8 Motorway scheme*

Figure 5-6: *Karst features - Cave at Emergence of Hammerhead River, Gort, Co. Galway*

5.6.4 Hydrological EIS Report

A detailed description of the surface water hydrology should be prepared for the Environmental

Impact Statement report. The report should present information on the topics outlined below :

- Introduction;
- Methodology – provide a detailed statement of how the study was carried out, with details of all data sources, the consultations undertaken, field surveys, findings from the hydrological survey, limitations in methodology and gaps in data;
- Regional Overview of geological and hydrological conditions within the original study area;
- Characterisation of the hydrological environment along the proposed route (receiving environment);
- Description of any wetland habitats, areas prone to flooding, surface water sources for local authority, private commercial / industrial and Group Water Schemes along the proposed route and existing discharges (licensed and/or unlicensed);
- Assessment of likely significant positive and/or negative impacts on the surface water environment in the vicinity of the proposed road alignment, arising principally from short-term (construction phase) and long-term (operational phase) changes in flow and quality. Cross reference the aquatic ecology section of the EIS as appropriate;
- Assessment of likely significant potential impacts on any surface sources used for water supply or leisure purposes along the proposed road alignment. Cross reference the Material Assets section of the EIS as appropriate;
- Mitigation measures required and assessment of residual impacts. Cross-reference the Ecological and Material Assets sections of the EIS as appropriate;
- References / List of Information Sources;
- Glossary, and
- Figures / Maps.

The following maps should accompany the Hydrological section of the Environmental Impact Assessment of the proposed road and should be based on detailed topographic mapping used for hydrological surveys:

- a Surface Water Features and Catchment Map (identifying abstraction points and the extent of their Source Protection Areas, springs);
- a Drainage and Flooding Map (existing and predicted / proposed);
- a Surface Water Flow Map (identifying baseline flows, discharge points (outfalls), gauging

stations and EIA flow monitoring locations), and

- a Surface Water Quality Map (identifying quality classification and EIA sampling locations).

Where the Soils and Geology and Hydrology sections of the EIS are prepared by separate Consultants, there will be particular need to ensure consistency between them in the presentation of baseline information, impact assessments and recommendations in the EIS.

5.7 Environmental Impact Assessment – Hydrogeology

5.7.1 Description of the Existing Hydrogeological Environment

The baseline EIS study builds on the information obtained during the previous Constraints Study and the Route Corridor Selection Study and is prepared using:

- relevant published and pre-existing information;
- feedback from consultations with statutory consultees, interested organisations and affected third parties;
- a walkover survey of the entire route and adjacent areas;
- a well survey of all affected landowners along, and in close proximity to, the proposed route;
- results of geophysical surveys undertaken along the proposed road alignment;
- results of ground investigations undertaken along the proposed road alignment;
- laboratory tests on soil and groundwater samples;
- in-situ and laboratory hydraulic testing;
- water level monitoring data, and
- analysis and interpretation of the collected data.

At the outset of the EIA process, the hydrogeological information obtained at Constraints Study and Route Corridor Selection Phases should be supplemented with information from other sources wherever possible. These sources may include:

- Groundwater well database of Geological Survey of Ireland;
- Groundwater Protection Schemes prepared by Geological Survey of Ireland (selected counties);
- Reports on Groundwater Catchment Studies, Aquifer Investigations, Regional Groundwater Resources, Karst, Groundwater Vulnerability and Quality prepared by the Geological Survey of Ireland, Local Authorities and/or Consultants;
- Memoirs accompanying Bedrock Geology Maps published by the Geological Survey of Ireland, and
- Academic / Professional Geological Publications and Seminar Proceedings.

At the outset of the EIA process, a comprehensive walkover should also be undertaken along the entire length of the proposed road scheme by the Consultant preparing the Hydrogeology section of the EIS in order to identify, locate and assess potential impacts on water supply wells and hydrogeological features that might be affected by the construction and operation of the road.

These surveys should cover the main route corridor and all other areas within the proposed landtake for the scheme (re-aligned local roads, link roads, access roads etc.) and extend to 250m to 500m beyond the proposed landtake boundary. This area may need to be increased where the proposed road footprint is extended for example, to make provision for link roads, re-aligned side roads, accommodation tracks or re-aligned watercourses or other related infrastructure. Notwithstanding this, professional judgement must also be applied in assessing whether the study area needs to be extended to take account of potentially significant impacts which could arise a greater distance away (e.g. at a source protection zone associated with a major wellfield or a groundwater dependent ecosystem).

The efficiency of the walkover survey and the quality of information obtained will be considerably enhanced by undertaking some preparatory work in advance to identify wells and groundwater features from existing databases.

Figure 5-7: *Dye-tracing is used to investigate the flow of groundwater in karst aquifers. In this instance, a fluorescent dye is added to upland feeder sinks to establish linkages and flows to springs further downstream.*

Low yielding wells, used mainly for domestic and farm water supply, are very common in Ireland outside the watermains networks of urban centres. Existing domestic and farm wells within the landtake boundary and up to at least 150m beyond should be identified (from the GSI database, walkover survey and well survey). Groundwater quality parameters and baseline water levels should be determined for all drinking water supply wells from the edge of the landtake boundary to a distance 150m beyond. A minimum of two rounds of monitoring should be undertaken, ideally around the time groundwater levels are at their seasonal maximum and minimum.

Groundwater quality testing for drinking water supply wells should be confined initially to the suite of indicator parameters identified by Table C, Part 1 of the Schedule to the *European Communities (Drinking Water)(No.2) Regulations, 2007, (S.I. No. 278 of 2007)*. The test parameters should also include Escherichia coli (E.coli) and hardness. When specifying groundwater quality tests, minimum detection limits should ideally be an order of magnitude less than the parametric value. Should testing indicate a potential problem with water quality associated with the road scheme proposal, more detailed follow-up testing should be undertaken as required.

Much information for the hydrogeological characterisation of a proposed road scheme can be obtained from boreholes drilled as part of the ground investigation contract. As ground investigation contracts are conventionally scoped, procured and managed by geotechnical engineers on the project design team, it is essential that the specialist consultant preparing the Hydrogeology (Groundwater) section of the EIS liaises closely with the design team to ensure that the ground investigation provides sufficient hydrogeological information for EIA purposes.

In planning the ground investigation for the road scheme, specific consideration should be given to sampling and testing of all subsoils, in-situ borehole permeability tests in soil and rock, pumping tests, installation and frequent monitoring of groundwater monitoring instruments (standpipes and piezometers). Consideration should also be given to the use of geophysical survey techniques, particularly along road cuttings and in karst limestone areas.

An outline of some conventional investigative techniques used to obtain the information outlined above is provided in Table 5.3. Note that this list is not intended to be exhaustive and other investigative techniques may be considered:

Hydrogeological Parameter	Method of Determination
Soil profile / depth of subsoil / depth to bedrock	Trial pits Cable percussion boreholes Percussive drillholes
Rock type, weathering, structure	Rotary core drillholes
Rock fracturing	Downhole acoustic or optical televiewer
Permeability	PSD analysis (of all subsoils) In-situ permeability tests Packer tests (rock) Pumping tests Laboratory tests (ideally on 'undisturbed' samples)
Buried cavities (in karst)	Geophysical surveys (microgravity, ground penetrating radar)
Flow paths in karst	Dye tracing
Groundwater level, hydraulic gradient, groundwater flow direction	Standpipes and/or piezometers in completed boreholes or drillholes (consider continuous monitoring with dataloggers at particularly sensitive sites)
Groundwater quality	Various laboratory techniques

Table 5.3: *Investigative Techniques for Assessment of Hydrogeological Impacts*

5.7.2 Hydrogeological Impact Assessment

The assessment of the hydrogeological impacts of a proposed road scheme should be based on the analysis and interpretation of data acquired during the Constraints Study and Route Corridor Selection phases and by hydrogeological investigations undertaken for EIA purposes. The prediction of impacts arising from a national road scheme must be based on transparent and objective (scientifically demonstrable) criteria.

The scheme for categorising, assessing and rating the significance of hydrological impacts should be based on that presented in Section 5.4 and Box 4-3 and 5-3 of these guidelines.

The assessment of hydrogeological impacts should not be limited to the area required for pre-construction, construction and post-construction purposes, but should be extended to include:

- water wells and hydrogeological features upgradient which could be affected by groundwater drawdown for the road scheme (typically a relatively small area), and
- water wells and hydrogeological features downgradient whose zones of drawdown or contribution may fall within the required landtake (potentially a much larger area).

The construction of a road scheme will not have a positive impact on the hydrogeological regime. Therefore, the available range of the degrees of impact will extend from neutral to severely negative.

A thorough assessment should be made of the potential impacts of the national road scheme on the existing groundwater flow regime, focussing specifically on implications for:

- Any high yielding springs and wells used for water supply and their surrounding Source Protection Zones (SPZs);
- Any significant natural hydrogeological features (including large springs or groundwater-fed SAC / NHA wetland sites);
- The dominant hydrogeological characteristics (aquifer classification) of the underlying strata; and
- Low-yielding wells used mainly for domestic and farm water supply.

In addition to assessing the potential impact of the road on the immediate area around the water supply source or the hydrogeological feature, it is also necessary to assess the potential impact on their Source Protection Zone (or zone of contribution). These zones can extend up to several kilometres, mainly upgradient, of the supply source or feature. This is also the case for groundwater dependent ecosystems where the zone of influence can extend for several kilometres.

Source Protection Zones for larger public wells may already have been determined by the Geological Survey of Ireland, Local Authorities or Group Water Schemes. If source protection zones have not been defined around major supply wells, an attempt should be made to define them for EIA purposes. An attempt should also be made to define Source Protection Zones for natural groundwater features such as springs and wetlands if this has not been done previously.

For water supply wells, wetlands and hydrogeological features of **low, moderate or high** importance, Source Protection Zones can be defined for EIA purposes using methods and guidance outlined in the publication 'Groundwater Protection Schemes' published by DoELG / EPA / GSI (1999). These methods, in order of technical sophistication, are:

- calculated fixed radius method;
- analytical methods, and
- hydrogeological mapping.

In general, the degree of sophistication used to determine the extent of the Source Protection Zones should increase according as the importance of the feature and/or the magnitude of any environmental impact increases.

Figure 5-8: *River resurgence at spring developed at base of a sequence of karstifiable rocks*

For water supply wells, wetlands and hydrogeological features of **very high or extremely high** importance, a more rigorous approach may be required to define the Source Protection Zones. At a minimum, this will require detailed hydrogeological mapping and investigation (field testing) of the local area. Where potential impacts are significant or profound, consideration should also be given to use of specialised numerical modelling software. In using numerical modelling software to establish Source Protection Zones, due regard should be had to:

- idealisation of ground conditions between the road and well or feature of interest;
- selection of representative hydrogeolgical input parameters;
- delineation and/or idealisation of hydrogeological boundaries;
- method of analysis, and
- sensitivity of the numerical model to small changes in input parameters.

An assessment should be made of potential changes (if any) in groundwater levels, groundwater flow volumes and groundwater vulnerability where road cuttings extend below the water table:

- within the Source Protection Zone (or zone of contribution) **upgradient** of a water well, spring, wetland or other hydrogeological feature; and
- **downgradient** of a water well, spring, wetland or other hydrogeological feature.

Typically the impact of a road cutting on a water well, spring, wetland or other hydrogeological feature increases:

- with increased depth of road cutting below water table (greater drawdown);

- with increased permeability of the soil and/or rock strata between the road cutting and groundwater feature;

- with increased lateral continuity and uniformity in soil and/or rock strata between the road cutting and groundwater feature, and

- in absence of any hydrogeological boundaries (such as watercourses) between the road cutting and water supply well or groundwater feature.

For road cuttings up-gradient or downgradient of a water well, spring, wetland or other hydrogeological feature of **low** or **moderate** importance, it will generally be sufficient to assess changes in groundwater levels (corresponding to a given drawdown in idealised subsoil / bedrock of uniform permeability) using guidance provided in technical publications such as the CIRIA publication *Groundwater Control – Design and Practice (C515)* (CIRIA, 2000). For road cuttings up-gradient in Source Protection Zones, changes in groundwater flow volumes to water wells, springs, wetlands or hydrogeological features can then be calculated having regard to assessed changes in groundwater levels and the reduction in groundwater recharge resulting from pavement sealing and installation of road drainage.

For water wells, springs, wetlands and hydrogeological features of high or very high importance, a more rigorous approach will be required to establish changes in groundwater levels and groundwater flow volumes. This will generally involve detailed hydrogeological mapping and investigation of the local area and/or use of specialised numerical modelling software, as discussed previously.

The 'dominant hydrogeological characteristic' is considered along the full length of the proposed road alignment. Owing to the variable nature of the geology across most of Ireland, there is no one impact assessment system that is appropriate for all major road schemes and a degree of professional judgement will have to be applied in undertaking the impact assessment, taking account of factors such as the aquifer classification, the depth of the unsaturated zone and the vulnerability of particular geological formations.

Given that low yielding wells for domestic and farm water supply are very common in rural Ireland, it is almost inevitable that any large road scheme will result in at least a small number of low-yielding water supply wells having to be abandoned. It can be assumed that:

- all live water supply wells within the footprint of the proposed road scheme need to be replaced;

- all live water supply wells within 100m of the footprint boundary will need to be assessed specifically for potential impacts on water level and quality, and

- all live water supply wells up to 150m from the scheme boundary or 50m beyond the zone of influence of cuttings will have to be monitored (for water level and quality) prior to, during and for a time (typically 12 months) after construction.

A systematic methodology for assessing the pollution risk associated with discharge of routine surface water run-off from the road carriageway to groundwater is presented in Method C of Annex 1 of HA216/06 (UK DMRB). In assessing the scale of risk to groundwater quality at a particular groundwater receptor (e.g. a water supply well or wetland habitat), this methodology takes account of key variables relating to:

- the source of the discharge (including traffic density, rainfall volume and intensity), and
- its pathway through the ground to the receptor (including soakaway geometry, depth of the unsaturated zone, intergranular or fracture flow in bedrock, effective grain size and the proportion of clay sized particles).

and applies a risk rating (low, medium or high) and weighting factor to each one in order to derive an overall risk score (expressed as a number). If the risk score for a particular groundwater receptor is:

- less than 150, the overall pollution risk from the proposed road scheme is assessed as low;
- if it lies between 150 and 250, the overall pollution risk is assessed to be medium, and
- if it exceeds 250, the overall pollution risk is assessed to be high.

In undertaking impact assessment, the Ecological Consultant should advise on potential impacts on aquatic habitats and the Consultant preparing the Material Assets section of the EIS advise on potential impacts on water supplies.

5.7.3 Hydrogeological Mitigation Measures

The impact of road construction on aquifers and groundwater resources can be minimised by applying sound design principles and by following good work practices. For groundwater, the following mitigation measures may be considered:

- where possible, re-align the road down-gradient or an appropriate distance up-gradient of the source protection area for high yielding water supply springs and wells and natural hydrogeological features;
- where possible, minimise the depth of road cutting within a source protection area or zone of contribution to minimise the impact on groundwater flows to downgradient springs, wells, wetlands and other hydrogeological features;
- where possible, minimise the depth of road cutting in order to ensure that its zone of contribution does not extend upgradient to a hydrogeological feature or wetland;
- where it is not possible to avoid running the road through the vulnerable part of the source protection area for a high yielding water supply well, spring or other hydrogeological feature, provide sealed drains or positive drainage systems;

- provide sealed drains or positive drainage systems along sections of road overlying the vulnerable parts of locally important or regionally important aquifers;

- provide site-specific measures to protect relatively small natural hydrogeological features such as springs, seeps or wetlands;

- assess the potential impact of re-grading small streams on nearby wells or springs;

- replace wells or provide alternative water supplies where low yielding wells have to be replaced;

- ensure that all surface water run-off discharged to groundwater via soakaways is passed through systems for settlement or filtration of suspended solids with the parallel effect of removing contaminants (certain heavy metals and hydrocarbons) associated with the suspended solids;

- groundwater monitoring may be appropriate in certain instances, instead of automatically providing specific mitigation measures. In these circumstances however, thresholds should be set that will trigger the introduction of pre-defined mitigation measures;

- specifying regular monitoring of groundwater during the construction period and for a defined period thereafter, following opening of the road scheme;

- all wells abandoned as part of the road scheme should be sealed and abandoned in accordance with *Well Drilling Guidelines* produced by the Institute of Geologists of Ireland. Ground investigation boreholes should be backfilled using bentonite or cement bentonite grout in accordance with the *Specification and Related Documentation for Ground Investigation* published by the Institution of Engineers of Ireland, and

- abandon obsolete ground investigation boreholes / water supply wells and springs in accordance with the appropriate guidelines.

In formulating hydrological mitigation measures, regard should be had to the requirements of the Water Framework Directive and Groundwater Directive. In developing mitigation measures, there should be co-ordinated and ongoing consultation with the River Basin Management Projects, the National Parks and Wildlife Service, local authorities, Group Water Schemes and Environmental Protection Agency as required.

Figure 5-9: *Example of a French Drain on M4*

In formulating mitigation measures, the Ecological Consultant should be consulted about measures in respect of aquatic habitats. The Consultant preparing the Material Assets section of the EIS should advise on measures in respect of water supplies. Further guidance on the treatment of aquatic ecology is provided in the NRA *Guidelines for Assessment of Ecological Impacts of National Road Schemes*.

5.7.4 Hydrogeological EIS Report

A detailed description of the hydrogeology along the proposed route should be prepared for the Environmental Impact Statement report. The report should present information on the topics outlined below:

- Introduction;
- Methodology – provide a detailed statement of how the study was carried out, with details of all data sources, the consultations undertaken, field and hydrogeological (well) surveys, results of geophysical surveys and ground investigations, permeability testing, soil / water sampling and analysis, limitations in methodology and gaps in data;
- Regional Overview of geological and hydrogeological conditions within the original study area;
- Hydrogeological characterisation of geological strata along the proposed road alignment (receiving environment). Describe the provenance (source) and type of permeability in the main aquifers and provide values for permeability, transmissivity, storage and specific capacity. For hydrogeological sites and features of low to moderate importance, it will generally be sufficient to assess these parameters on the basis of relevant published data. Where sites are of greater importance, these parameters should ideally be determined from field investigations;

- Outline the hydraulic conditions (unconfined, leaky or confined) in each of the aquifers and comment on the possible presence of artesian conditions in any strata;
- Assessment of the groundwater vulnerability of the aquifers along the road alignment;
- Assessment of Karst and Karst Featurs in Limestone Areas along road alignment;
- Description of the groundwater conditions at any wetland habitats, large springs, holy wells and groundwater sources for local authority, commercial/industrial water supply and Group Water Schemes along the proposed road alignment. Compile information on Source or Aquifer Protection Areas along the proposed route;
- Compilation of the results of the well survey of low yielding domestic and farm wells;
- Compilation of water quality test data and water levels on groundwater samples from ground investigation boreholes and low yielding wells;
- Impact assessment of any high yielding groundwater sources used for water supply and/or significant natural hydrogeological features along the proposed route. Cross reference the Ecological and Material Assets sections of EIS as appropriate;
- Impact assessment on the strata along the full length of the proposed route, with the aid of the information compiled on the geology, aquifer classification, hydraulic conditions, water table elevation and groundwater vulnerability. Cross reference the Ecological and Material Assets sections of EIS as appropriate;
- Mitigation Measures required and assessment of residual impacts;
- References / List of Information Sources;
- Glossary, and
- Figures / Maps.

The following maps should accompany the Hydrogeological section of the Environmental Impact Assessment of the proposed road:

- a Bedrock Geology Map (identifying karst areas / hydrogeological features, where present);
- a Depth to Bedrock Map showing depth /elevation of bedrock along the road alignment;
- a Subsoil Map;
- *an Aquifer Map* – identifying aquifer types and hydraulic conditions (confined or unconfined);

- an Aquifer Vulnerability Map;
- a Water Table Map showing the depth and/or elevation of the water table along the route and the direction of groundwater flow;
- Hydrogeological Features Map to include include the locations of any major springs and water supply boreholes, wetland areas, karst features and areas covered by either local authority or Group Water Scheme mains. This map should include locations of all low yielding wells along the proposed route and the adjoining area, and
- A Groundwater Vulnerability Map of the area. This map should also show the extent of established / inferred / assessed Source Protection Areas for high yielding groundwater sources used for water supply and/or significant natural hydrogeological features.

Where the Soils and Geology and Hydrogeology sections of the EIS are prepared by separate Consultants, there will be particular need to ensure consistency between them in the presentation of baseline information, impact assessments and recommendations in the EIS.

A summary flowchart summarising the requirements for Environmental Impact statements is presented in Figure 5.1.

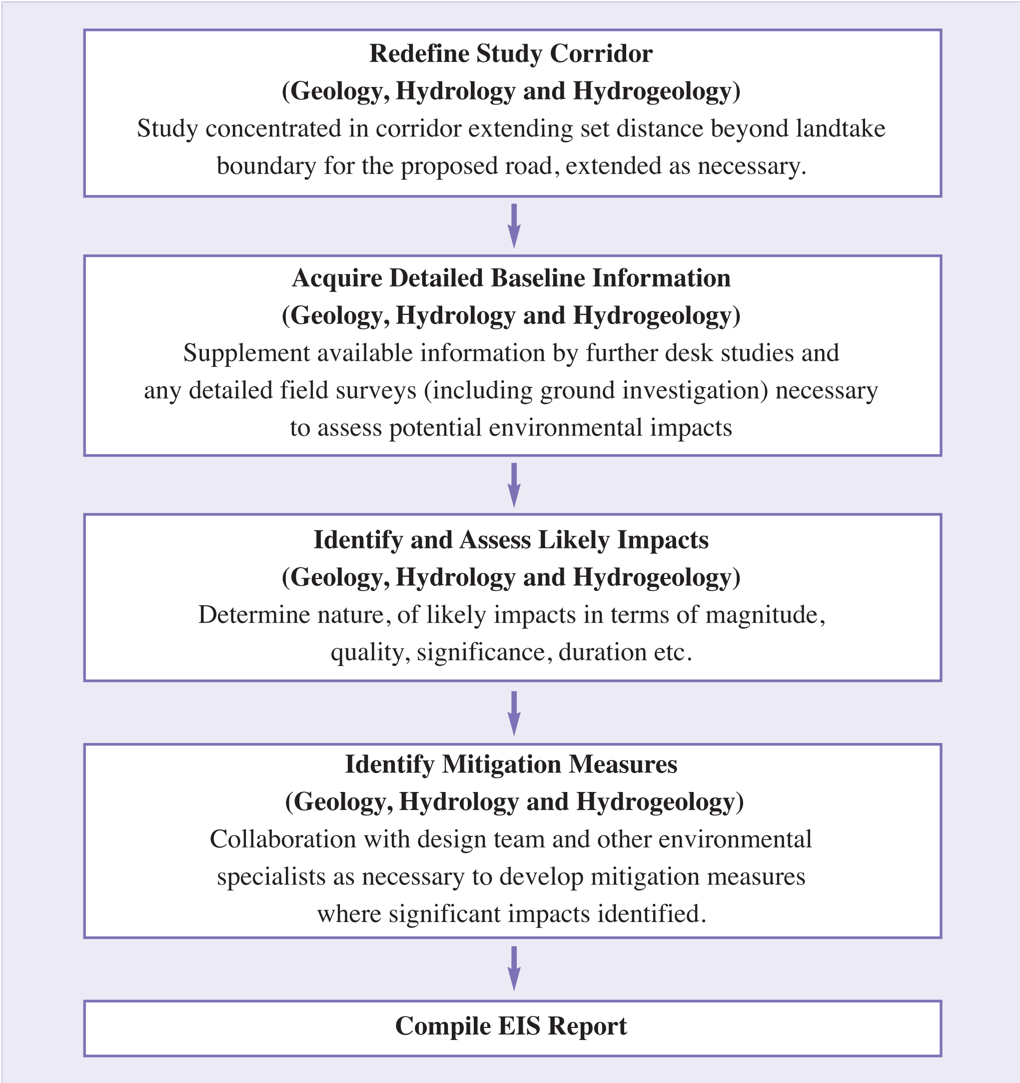

Figure 5-10: *Flowchart summarising Environmental Impact Statement Inputs*

Box 5.1: CRITERIA FOR RATING IMPACT SIGNIFICANCE AT EIA STAGE - Estimation of Magnitude of Impact on Soil / Geology Attribute

Magnitude of Impact	Criteria	Typical Examples
Large Adverse	Results in loss of attribute	Loss of high proportion of future quarry or pit reserves Irreversible loss of high proportion of local high fertility soils Removal of entirety of geological heritage feature Requirement to excavate / remediate entire waste site Requirement to excavate and replace high proportion of peat, organic soils and/or soft mineral soils beneath alignment
Moderate Adverse	Results in impact on integrity of attribute or loss of part of attribute	Loss of moderate proportion of future quarry or pit reserves Removal of part of geological heritage feature Irreversible loss of moderate proportion of local high fertility soils Requirement to excavate / remediate significant proportion of waste site Requirement to excavate and replace moderate proportion of peat, organic soils and/or soft mineral soils benath alignment
Small Adverse	Results in minor impact on integrity of attribute or loss of small part of attribute	Loss of small proportion of future quarry or pit reserves Removal of small part of geological heritage feature Irreversible loss of small proportion of local high fertility soils and/or high proportion of local low fertility soils Requirement to excavate / remediate small proportion of waste site Requirement to excavate and replace small proportion of peat, organic soils and/or soft mineral soils beneath alignment
Negligible	Results in an impact on attribute but of insufficient magnitude to affect either use or integrity	No measurable changes in attributes
Minor Beneficial	Results in minor improvement of attribute quality	Minor enhancement of geological heritage feature
Moderate Beneficial	Results in moderate improvement of attribute quality	Moderate enhancement of geological heritage feature
Major Beneficial	Results in major improvement of attribute quality	Major enhancement of geological heritage feature

Box 5.2: CRITERIA FOR RATING IMPACT SIGNIFICANCE AT EIA STAGE - Estimation of Magnitude of Impact on Hydrology Attributes

Magnitude of Impact	Criteria	Typical Examples
Large Adverse	Results in loss of attribute and /or quality and integrity of attribute	Loss or extensive change to a waterbody or water dependent habitat Increase in predicted peak flood level >100mm[1] Extensive loss of fishery Calculated risk of serious pollution incident >2% annually[2] Extensive reduction in amenity value
Moderate Adverse	Results in impact on integrity of attribute or loss of part of attribute	Increase in predicted peak flood level >50mm[1] Partial loss of fishery Calculated risk of serious pollution incident >1% annually[2] Partial reduction in amenity value
Small Adverse	Results in minor impact on integrity of attribute or loss of small part of attribute	Increase in predicted peak flood level >10mm[1] Minor loss of fishery Calculated risk of serious pollution incident >0.5% annually[2] Slight reduction in amenity value
Negligible	Results in an impact on attribute but of insufficient magnitude to affect either use or integrity	Negligible change in predicted peak flood level[1] Calculated risk of serious pollution incident <0.5% annually[2]
Minor Beneficial	Results in minor improvement of attribute quality	Reduction in predicted peak flood level >10mm[1] Calculated reduction in pollution risk of 50% or more where existing risk is <1% annually[2]
Moderate Beneficial	Results in moderate improvement of attribute quality	Reduction in predicted peak flood level >50mm[1] Calculated reduction in pollution risk of 50% or more where existing risk is >1% annually[2]
Major Beneficial	Results in major improvement of attribute quality	Reduction in predicted peak flood level >100mm[1]

[1] *refer to Annex 1, Methods E and F, Annex 1 of HA216/06*
[2] *refer to Appendix B3 / Annex 1, Method D, Annex 1 of HA216/06*

Box 5.3: CRITERIA FOR RATING IMPACT SIGNIFICANCE AT EIA STAGE - Estimation of Magnitude of Impact on Hydrogeology Attributes

Magnitude of Impact	Criteria	Typical Examples
Large Adverse	Results in loss of attribute and /or quality and integrity of attribute	Removal of large proportion of aquifer Changes to aquifer or unsaturated zone resulting in extensive change to existing water supply springs and wells, river baseflow or ecosystems Potential high risk of pollution to groundwater from routine run-off[1] Calculated risk of serious pollution incident >2% annually[2]
Moderate Adverse	Results in impact on integrity of attribute or loss of part of attribute	Removal of moderate proportion of aquifer Changes to aquifer or unsaturated zone resulting in moderate change to existing water supply springs and wells, river baseflow or ecosystems Potential medium risk of pollution to groundwater from routine run-off[1] Calculated risk of serious pollution incident >1% annually[2]
Small Adverse	Results in minor impact on integrity of attribute or loss of small part of attribute	Removal of small proportion of aquifer Changes to aquifer or unsaturated zone resulting in minor change to water supply springs and wells, river baseflow or ecosystems Potential low risk of pollution to groundwater from routine run-off[1] Calculated risk of serious pollution incident >0.5% annually[2]
Negligible	Results in an impact on attribute but of insufficient magnitude to affect either use or integrity	Calculated risk of serious pollution incident <0.5% annually[2]

[1] *refer to Annex 1, Method C, Annex 1 of HA216/06*
[2] *refer to Appendix B3 / Annex 1, Method D, Annex 1 of HA216/06*

Box 5.4: Rating of Significant Environmental Impacts at EIA Stage

		Magnitude of Impact			
		Negligible	**Small**	**Moderate**	**Large**
Importance of Attribute	**Extremely High**	Imperceptible	Significant	Profound	Profound
	Very High	Imperceptible	Significant / Moderate	Profound / Significant	Profound
	High	Imperceptible	Moderate / Slight	Significant / Moderate	Severe / Significant
	Medium	Imperceptible	Slight	Moderate	Significant
	Low	Imperceptible	Imperceptible	Slight	Slight / Moderate

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APPENDICES

APPENDIX A : SOILS AND GEOLOGY, THE IRISH GEOLOGICAL ENVIRONMENT

A1 INTRODUCTION

A different meaning is often attached to the word '*soil*' by various specialists. Environmental and agricultural scientists generally understand the word *'soil'* refer to the fertile, organic rich layer which occurs on the surface of the Earth and the underlying layers which interact with it in terms of nutrient, ion, water and heat exchange. Using this definition, the depth of the soil layer is typically 0.3m to 1.0m thick. Geologists and engineers, on the other hand, often understand the word *'soil'*to refer to all unconsolidated (non-lithified) organic and inorganic deposits which occur above bedrock.

For the purposes of these guidelines, the term *'soil'* is used to refer to the unconsolidated, organic material closest to the Earth's surface. The term *'subsoil'* is used to refer to all other unconsolidated (non-lithified) materials which occur above bedrock.

The geological environment can be conveniently divided into solid geology, composed of lithified material (of Precambrian to Tertiary age) and drift geology, mostly composed of unlithified material (of Quarternary age). It should be noted, however, that much of the Tertiary sedimentary lithologies in Ireland may be unlithified or only partly lithified.

A2 TOPOGRAPHY AND LANDSCAPE

Ireland has frequently been described as bowl shaped, with elevated topography around the margins of the island and the central part composed of flatter lowlands. The present-day topography has largely been shaped by the interaction of the various Quarternary ice advances on the pre-Quarternary (Tertiary) landform and the underlying rock foundation.

In the south-east, the Leinster Granite forms the backbone of the range of mountains extending from south Dublin thorough Wicklow into Carlow, Wexford and Waterford. In the south and south-west, the Devonian "Old Red Sandstone" mountains form a number of mountain ranges extending from Waterford to Kerry. Upper Carboniferous sandstones, mudstone / shales and limestones form low hills and cliffs along the coast between north Kerry and north Clare.

The solid geology changes across Galway Bay, with the Precambrian rocks of west Galway and north Mayo, and the Ordovician and Silurian rocks of south Mayo forming a number of mountain ranges along the west coast. The Precambrian metasediments and granites of the Ox Mountains form the higher ground close to the coasts of north Mayo and west Sligo. Carboniferous rocks again form hills and mountains along the north Sligo and Leitrim coasts, with Precambrian metamorphic rocks and Caledonian Granites forming the mountains of Donegal and Tyrone.

In the north-east, the Tertiary basalts cap the uplands of the Antrim Plateau. The circle of coastal uplands and mountains is more or less completed by the Tertiary granite intrusives of the Mourne Mountains, Slieve Gullion and the Carlingford Mountains.

The central plain of Ireland is largely underlain by Lower Carboniferous rocks with a number of ranges of hills or mountains in the southern midlands where resistant Devonian and Silurian inliers are present. The midlands are extensively covered by glacial tills and sands and gravels, mostly derived from Carboniferous rocks, predominantly limestone

A3 BEDROCK GEOLOGY

It has been observed that the degree of geological diversity on the island of Ireland is relatively high, given its limited geographical extent. Rock from every geological period is present in Ireland and the rocks formed during these periods show considerable diversity. A brief overview of the principal geological formations and the associated rock types is presented below.

Precambrian

Precambrian rocks in Ireland are mainly present in the north and west of Ireland, forming the upland area in west Galway, west Mayo, Sligo (Ox Mountains) and Donegal, although a small outlier of Precambrian is present in south-east Wexford. The oldest rocks in Ireland are those of the island of Inishtrahull, Co. Donegal which have been determined to be 1700 million years old. The Precambrian sequences are composed of high-grade metamorphic rocks, derived from the alteration of sedimentary and igneous rocks by extremes of temperature and pressure. Rock types present include schists, gneisses and quartzites formed from mudstones, siltstones and sandstones, marbles formed from limestones and amphibolites and metabasites formed from metamorphosed igneous rocks. The rocks are generally hard and strong, but may be strongly foliated.

Cambrian

Cambrian rocks are present in east and south-east Ireland. A large block of Cambrian rocks is exposed in the Bray – Roundwood – Newcastle area of Wicklow and a belt of Cambrian rocks trends south-west from Cahore Point to Ballyteigue Bay in Co. Wexford. A small inlier of Cambrian rocks is also present trending south-west from Rosslare. The rocks are composed of greywackes and slates with thick interbedded quartzites. These rocks tend to be strong to very strong and can be highly abrasive due to their high quartz content. They can be strongly tectonised and may be locally deeply weathered.

Lower Palaeozoics (Ordovician and Silurian)

Rocks of Ordovician and Silurian age are present in south Mayo, south-east Ireland, as a belt of rocks extending to the north-east from Co. Roscommon to Co. Down through south Leitrim, Cavan and Monaghan (Longford – Down Massif) and in a series of inliers in the southern part of the Irish midlands. These rocks are generally composed of mudstones, siltstones and sandstones, with significant thicknesses of igneous or volcanic-derived material present in south-east Ireland and south Mayo. Some mudstones may have been altered by low-grade metamorphism to slates.

The rocks are generally strong, but many mudstones may be weak and there may be significant local variation in the properties of the rocks, particularly where strong competent lithologies are interbedded with weaker ones. The sequence is frequently strongly folded and dips may be at a high angle to the surface.

Devonian

Devonian rocks are exposed in a thick rock succession forming the sandstone mountains of the south and south-west (Munster Basin), around the uplands in the southern midlands, in the Castlebar area and in the Curlew Mountains. During the Devonian period, parts of Ireland comprised rapidly uplifted areas of land which eroded rapidly producing huge quantities of clastic sediments which were deposited in arid to semi-arid environments. Large thicknesses of the Devonian mudstones, siltstones, sandstones and conglomerates occur, and are well exposed, in the sandstone mountains of the south-west as they are stronger and more erosion resistant that the softer Carboniferous rocks in the valley below. The sediments are predominantly red in colour, leading to the original naming of these rocks as the "Old Red Sandstone". Volcanic rocks are interbedded with the red clastics in the Curlew Mountains and in Counties Cork, Kerry and Limerick.

Carboniferous

Rocks of the Carboniferous period are the most common in Ireland, covering approximately 45% of the total land surface. They occur in every county in the State with the exception of Co. Wicklow. Much of the midlands and the north-west is underlain by rocks of Carboniferous age. The lower Carboniferous rocks are composed of a mixed sequence of shales, siltstones, sandstones and limestones, passing up into a thick sequence of limestones formed in both shallow water ("shelf") and deep water ("basin") environments. Thick shales and sandstones and some gypsum are present within the sequence in the north-west.

This lithologically mixed Lower Carboniferous succession is, in turn, overlain by thick sequences of river delta sandstones, siltstone and mudstones which contain coals in a number of areas, such as the Castlecomer, Slieve Ardagh, Connaught, Coalisland and Ballycastle coalfields. In the Fintona area of Tyrone, terrestrial redbeds (predominantly iron oxide-stained sandstones, conglomerates and siltstones) of Carboniferous age are present.

The Carboniferous limestone lithologies are diverse in nature, with wide variations in bedding thickness, shale content and grain size. These variations have resulted in a wide range of rock properties which affect the excavatability and re-use of the rock, and also result in a wide range of permeability (and to a lesser extent, porosity), which affects the hydrogeological properties of the limestones.

Permian

Permian rocks are largely only present in north-eastern Ireland with the exception of a localised outlier near Kingscourt, Co. Cavan and a small outlier in south-east Co. Wexford. At Kingscourt, the sequence is composed of approximately 550m of sandstones and mudstones with thick gypsum horizons which are currently being mined. In the Wexford outcrop, a sequence of terrestrial redbeds is present.

Triassic

Rocks of Triassic age are mainly present in north-eastern Ireland, where they are composed mainly of sandstones and mudstones with thick halite (salt) horizons. In the Kingscourt area, a sequence of Triassic sandstones overlies the gypsum-bearing Permian rocks.

Jurassic

Rocks of Jurassic age are mainly present in north-eastern Ireland, where they are composed mainly of calcareous mudstones and limestones.

Cretaceous

Rocks of Cretaceous age are mainly present in north-eastern Ireland, where they are composed of the Hibernian Greensands and the overlying Ulster White Limestones ("chalk") exposed around the Antrim Plateau. A small outlier of Cretaceous sediments is preserved at Ballydeanlea, near Killarney.

Tertiary

Rocks and sediments of Tertiary age are mainly confined to north-east Ireland where a thick basalt sequence (the Antrim Basalts) are locally overlain by largely lacustrine clays with lignites of the Lough Neagh Group. Large igneous intrusive bodies such as the Mourne Granites and the Slieve Gullion – Carlingford complex are also of Tertiary age. In the rest of the island, intrusive igneous rocks of Tertiary age are present in the form of igneous dykes, probably conduits for erupted rocks which have been subsequently eroded.

Tertiary sediments are also widely present across Ireland as locally preserved infills in depressions in the bedrock surface, predominantly in limestone areas, where dissolution of the limestone bedrock produced large karstic depressions which were subsequently infilled by Tertiary sediments. During the Ice Age, most of these Tertiary deposits were eroded by the ice.

A summary of the geological formations of Ireland is presented in a summarised (by period) tabular format in Table A-1, together with an indication of the environmental and engineering issues typically associated with them.

A summary bedrock geology map, based on the geological age of the rock, is shown in Figure A-1. The same map has been modified to generate a bedrock geology map based on principal rock type in Figure A-2.

Geological Era	Age	Period	Main Rock Types	Environments	Location	Engineering and Environmental Significance
Cainozoic	0.012	Quaternary (Holocene)	Recent deposits	Modern climate	Widespread	Deposit types dominate soft ground areas – peats, silts and unconsolidated clays.
	1.8	Quaternary (Pleistocene)	Tills, sands and gravels	Ice Age	Widespread	Sands and gravels often important and vulnerable aquifers.
	65.5	Tertiary	Basalts, igneous intrusions. Terrestrial, fluvial and lacustrine sediments	Volcanoes, terrestrial deposits, lakes and swamps	Extensive igneous rocks in North-East Ireland (Antrim, Down, Armagh and Louth). Sediments locally present in many areas	Sediments frequently preserved below Quaternary deposits in bedrock depressions (predominantly karstic in nature). May be unconsolidated. Difficult to detect. Igneous rocks strong, resistant lithologies. Excavation difficult. High re-use value.
Mesozoic	145	Cretaceous	White limestone (“chalk”) and marine sandstones	Shallow “chalk” sea	Northern Ireland; Ballydeanlea, Co. Kerry	Not encountered on NRA Schemes.
	199	Jurassic	Mudstones and limestones	Shallow seas and land	Northern Ireland	Not encountered on NRA Schemes.
	251	Triassic	Red sandstones, siltstones and mudstones	Deserts, playa lakes, shallow marine (New Red Sandstone)	Northern Ireland	Not encountered on NRA Schemes.
Palaeozoic	299	Permian	Red sandstones, siltstones and mudstones with thick salt and gypsum		North-East Ireland, Kingscourt and South-East Wexford	Restricted in extent. Evaporites and mudstones have low re-use value. Sandstones form important aquifers.
	359	Carboniferous	Mudstones, siltstones and sandstones with coals overlying thick limestone, dolomite and shales. Igneous rocks in Limerick and midlands.	Tropical seas and river deltas and swamps	Widespread, underlying over 45% of total land area. Principally in Midlands, North-West and Valleys of Cork and Waterford. Occurs in every county except Wicklow.	Mixed sequences, excavated rock may be highly variable – some materials may not be re-usable, other material may provide high value aggregate. Extremely karstified in certain areas and hosts many important aquifers.
	416	Devonian	Red sandstones, siltstones and mudstones. Igneous intrusions.	Mountains, rivers and deserts (Old Red Sandstone)	Sandstone mountains of the South and South-West ; margins of the southern Midland hills, Curlew Mountains, Tyrone and Fermanagh	Generally strong, resistant lithologies. Excavation may be difficult, strong material may have high value in reuse. Some sandstones are important aquifers in south and south midlands.
	488	Lower Palaeozoics (Ordovician and Silurian)	Marine sandstones, siltstones and mudstones; volcanic rocks	Ocean basins and volcanic islands	Leinster massif and the Southeast, Longford – Down, Tyrone Volcanics, Charlestown and North Mayo, southern Midland hills	Strong, resistant lithologies interbedded with weak lithologies. Excavation may be difficult; stronger material may have high re-use value. May be structurally complex. Volcanics can be important aquifers.
	542	Cambrian	Sandstone, slate and quartzites	Muds, silts and sandstones deposited in shallow seas	South-East	Generally strong, resistant lithologies. Excavation may be difficult, material may have high re-use value. May be structurally complex.
Precambrian			Schist, gneisses, quartzites and marbles. Igneous intrusions.	Ancient continents	Mainly northwest and west (Galway, Mayo, north Leitrim, Donegal, Sperrins, northeast Antrim	Generally strong, resistant lithologies. Excavation may be difficult, material may have high value in re-use. Normally structurally complex, rocks may be highly foliated.

Table A-1: *Geological Time Chart for Ireland*

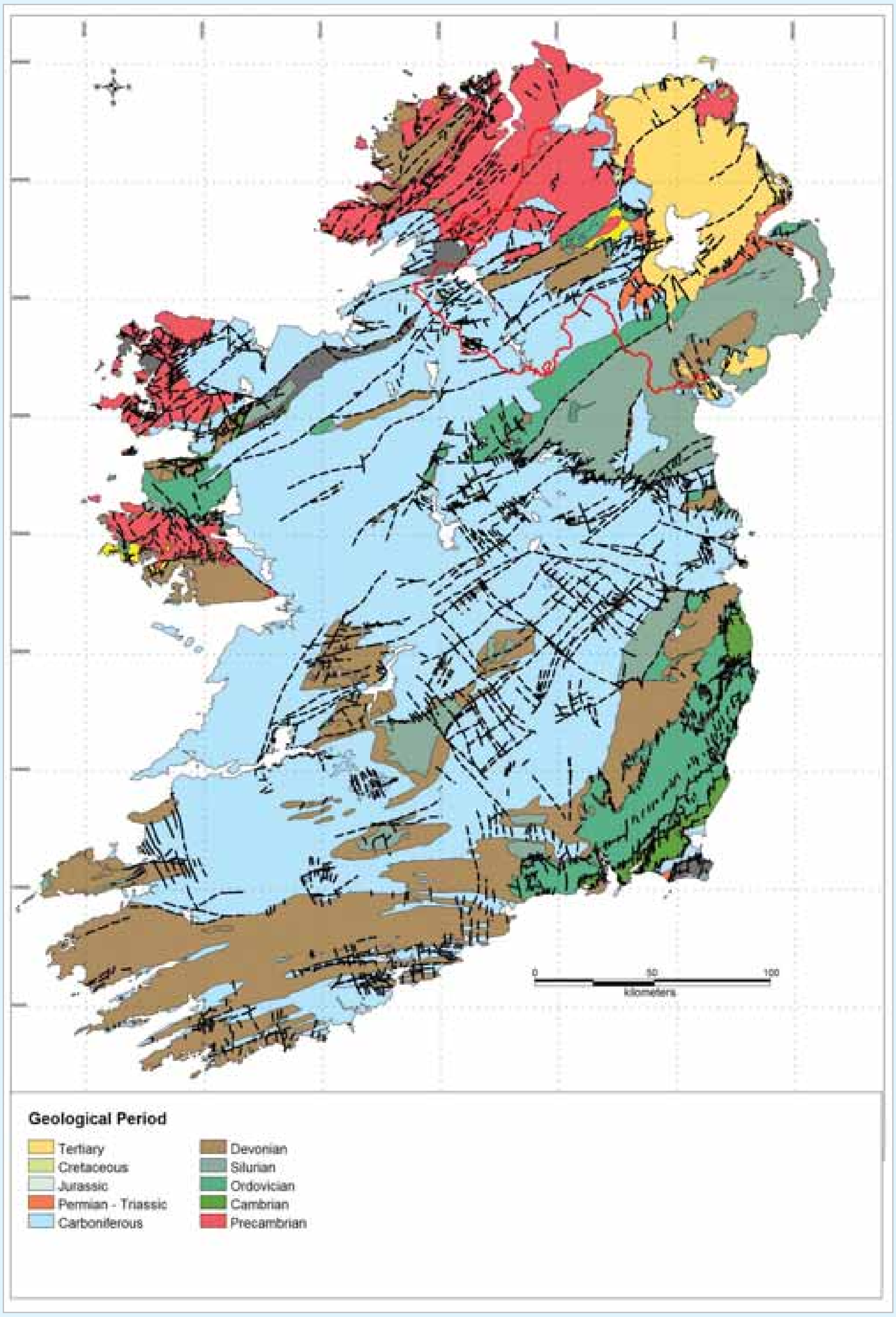

Figure A-1: *Bedrock Geology Map of Ireland – Geological Age. Modified Version of 1:500,000 scale Bedrock Geological Map of Ireland published by Geological Survey of Ireland.*

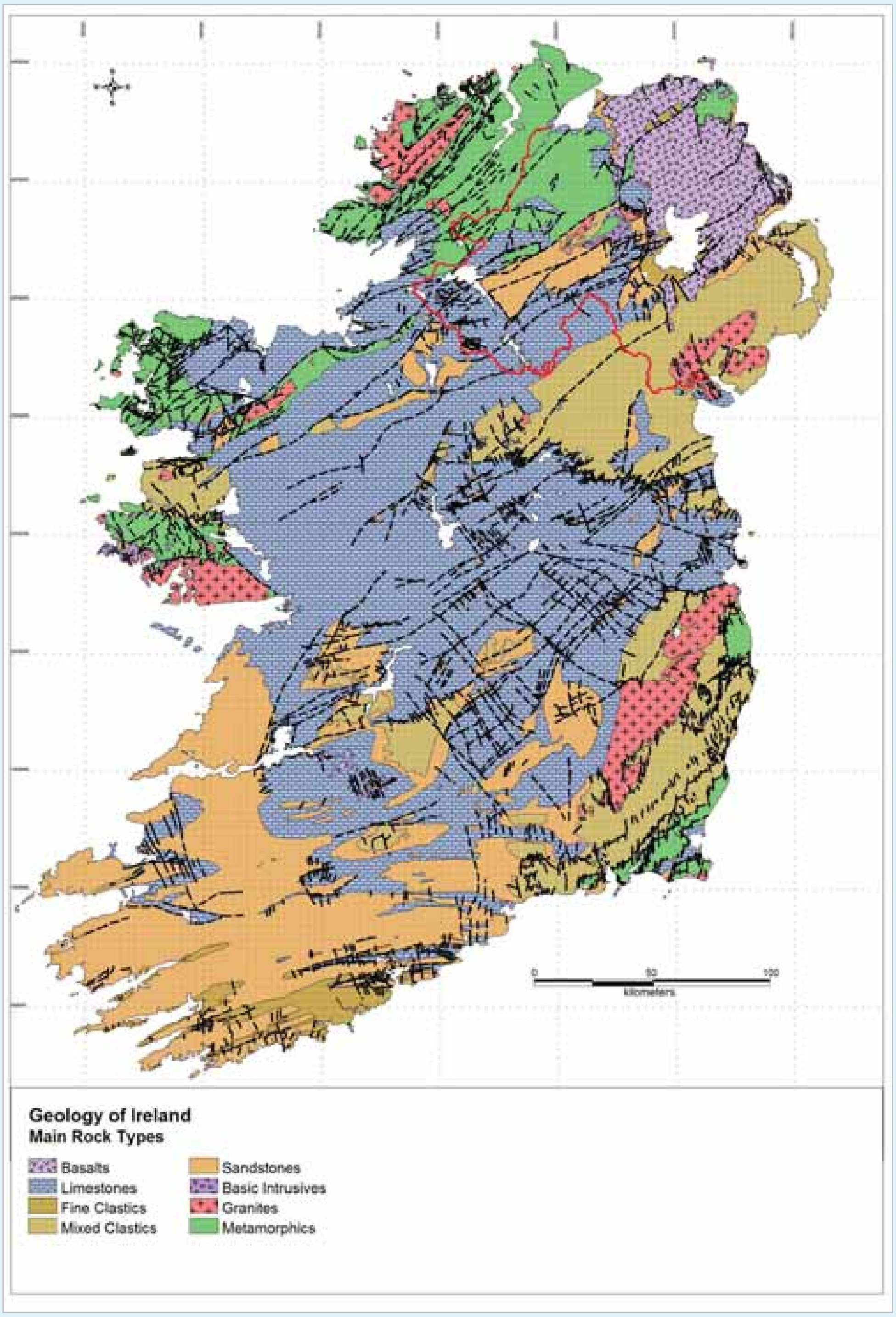

Figure A-2: *Bedrock Geology Map of Ireland – Principal Rock Type. Modified Version of 1:500,000 scale Bedrock Geological Map of Ireland published by Geological Survey of Ireland*

A4 ROCK MASS CHARACTERISTICS

Structure

The rocks of Ireland are extensively fractured, both by faults, where the rocks have been displaced across fractures, and joints, where no displacement has occurred. The broad structural grain within the rocks of Ireland was initially developed during the major mountain building period of the Caledonian Orogeny which occurred 440 to 410 million years ago. The structures and structural trends developed at that time are typically oriented south-west to north-east, with localised north–south structures and some north-west oriented accommodation structures. The south-west to north-east trends are referred to as being Caledonian in orientation.

The Caledonian structures were reactivated by earth movements in the subsequent Devonian and Carboniferous periods. A major phase of tectonism in the late Carboniferous, termed the Variscan Orogeny, superimposed a predominantly east – west trend on the rocks in southern Ireland, termed the Variscan trend. The major structures and trends developed during the Caledonian and Variscan have been repeatedly reactivated by younger earth movements. Various phases of movement, occurring at different times, can be identified on a number of major fault systems.

Difficult or broken ground is commonly associated with fault zones. The nature and orientation of the discontinuities in a rock mass will influence the stability and excavatability of rock cuttings developed on road schemes. Significant weathering is often associated with discontinuities in bedrock.

The structural framework of faults and joints within the generally old and indurated Irish rocks often forms the main pathway for water movement through the ground. The fracture system within the rock generally exerts a strong control on aquifer characteristics and the groundwater flow regime. More detailed information on aquifer characteristics and behaviour are presented in Appendix C1 of these guidelines.

Weathering

Weathering of bedrock can be highly variable in extent and depth. In soluble limestone areas, karst related weathering may develop to significant depths. In areas of insoluble bedrock, the depth and extent of weathering will depend on the lithologies present, the structure of the rock mass, the duration of exposure to weathering agents and localised rates of erosion.

While weathering occurs more rapidly in upland areas, the weathered material also erodes more rapidly. Permeable rocks allow a greater rate of water penetration, enhancing the rate of weathering. In contrast, impermeable lithologies resist weathering. Where the rocks are tightly folded, or strongly fractured, high angle discontinuities may allow deep penetration of water into the rock mass, allowing a deep weathering profile to develop.

In areas which were extensively glaciated during the most recent (Midlandian) Ice Age, the weathered rock will generally have been removed by glacial action. Where the exposed bedrock was subsequently covered with glacial sediments, the extent of post-glacial weathering would have been reduced. In contrast, areas which were not covered by the Midlandian ice sheets, will have been exposed to weathering agents and processes for a longer time and a deeper weathering profile may have developed.

A5 DRIFT GEOLOGY

The Quaternary era can be divided into two sub-divisions, the Pleistocene, from approximately 1.8 million years to 10,000 years ago, and the Holocene, from approximately 10,000 years ago to the present day. The Pleistocene period comprised a number of glacial and interglacial cycles, of which the most recent, termed the 'Midlandian', came to a gradual end between 17,000 and 10,000 years ago.

The last major ice advance recorded in Ireland is generally thought to have covered Ireland north of a line between Limerick and Wexford (known as the Southern Irish end moraine) as well as the upland areas of West Cork and Kerry, where a smaller ice cap developed. As a result of the gradual northward retreat of the ice sheets, the south and south-east of Ireland have been free of ice for a longer period than northern areas, with the exception of some upland areas such as the Comeragh and Galtee Mountains where small local glaciers occurred. As the southern and south-eastern areas of the country have been free of ice cover for a longer time, periglacial processes have been active in these areas and have produced periglacial landforms.

Pleistocene

Pleistocene deposits in Ireland are composed of materials produced by the erosion of the landscape by the grinding action of the advancing ice sheets. The eroded materials were subsequently transported by the ice and either laid down beneath the ice forming glacial till deposits, or in front of or to the side of the ice sheets, as moraines. The composition of glacial till varies widely, though it typically occurs as intermixed well-graded sandy gravelly clays or clayey gravel with cobbles and boulders. Moraines typically comprise mixed deposits of sand and gravel. These soils are generally good foundation soils for earth embankments and, where excavated at depths in excess of 1m to 2m can generally be re-used in embankment construction.

As the ice sheets gradually retreated toward the end of the last glacial stage, large quantities of meltwater were produced, which transported and deposited glacially derived sediments such as glacial outwash deposits, deltaic deposits and fluvio-glacial deposits, which principally comprise intermixed sand and gravel. Landforms produced by the ice and associated meltwater include corries, glaciated valleys, drumlins, eskers, moraines, kettle holes, pingos and kames.

Holocene

Holocene deposits in Ireland comprise all those sediments laid down during the 10,000 years since the end of the last glacial period in Ireland. These mainly comprise river and lake sediments such as alluvium, lacustrine and estuarine silts and clays, peat and coastal sand deposits. Holocene deposits are typically unconsolidated and soft or loose in nature and prone to large total and/or differential settlement if road embankments are constructed directly on top of them (without structural support or prior ground improvement). The total thickness of soil deposits is highly variable, being typically thin or absent in upland areas or areas with steep topography, and thickest along valley floors and river flood plains

Teagasc (2004) produced regional sub-soil maps for each county in the State, identifying the mineral soil type which occurs at or close to the ground surface. A modified summary map is shown in Figure A-3.

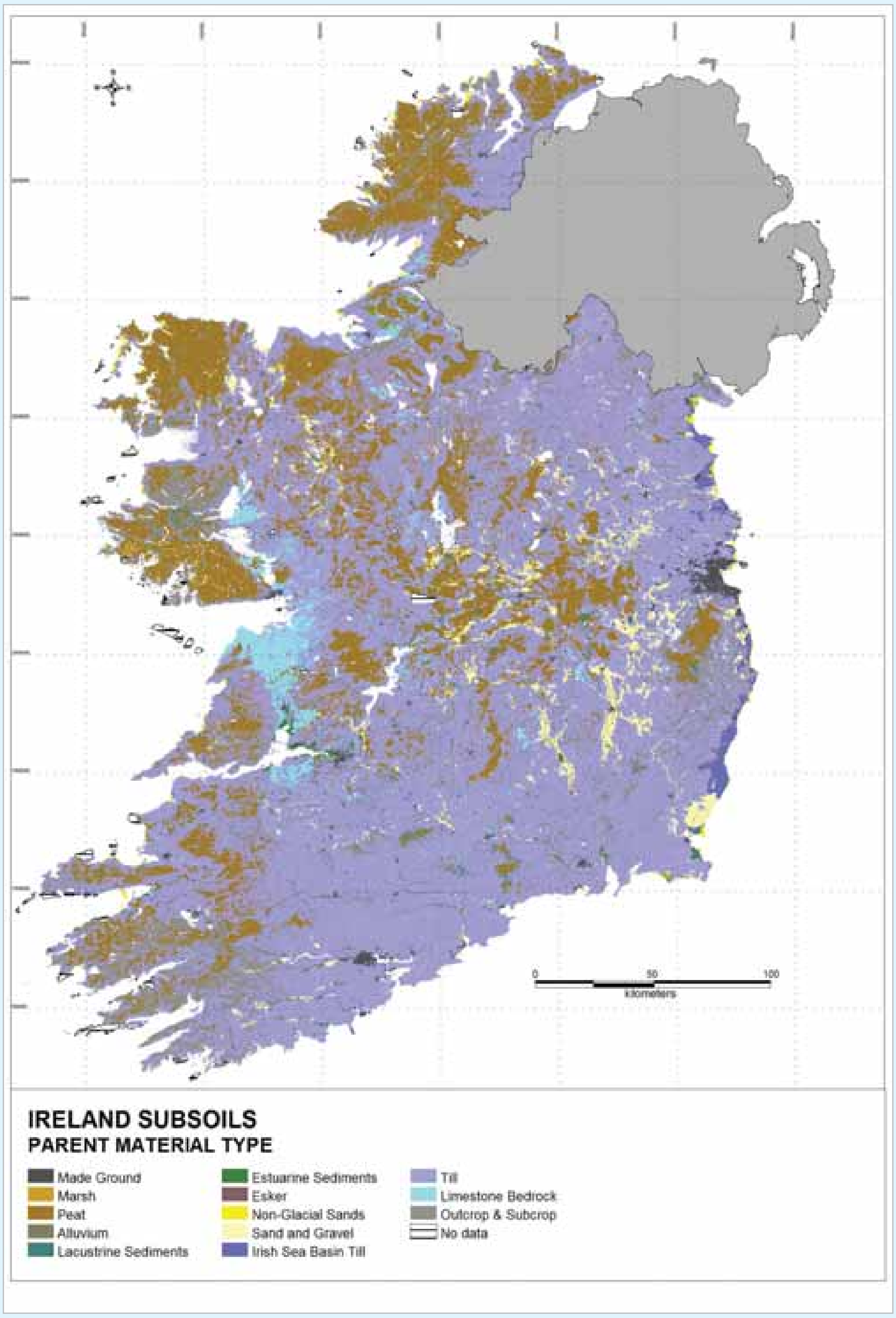

Figure A-3: *Subsoil Map of Ireland. Modified Version of Subsoil Mapping of Ireland published by Teagasc.*

A6 PEAT

Peat covers approximately 16% of the land surface of Ireland. The development of peat bogs was initiated at the end of the last ice age and was influenced by many factors including climate, hydrology, drainage, geology and nutrient status. Over recent centuries however, many bogs have been significantly modified and degraded by human activity, with the result that only 20% of Ireland's bogs retain any wildlife or conservation value. The three basic peat formations which occur in Ireland are blanket bogs, raised bogs and fens.

Blanket bogs occur extensively along the western seaboard and in upland areas and often obscure the underlying topography. Blanket bogs above 200mOD are classified as Mountain type while those below 200m OD are classified as Atlantic type. The development of blanket peat was initiated when heathers and rushes colonised areas underlain by water-logged, nutrient-poor and acid-rich mineral soils. As vegetation died, it decayed very slowly in a relatively wet, cool, anaerobic environment. Gradually, over time, the decaying vegetation extended laterally outwards and accumulated vertically upwards, leading to the formation of blanket bogs.

Raised bogs occur extensively across the Irish Midlands. The initial development of these bogs was associated with the growth and decay of vegetation in shallow water environments, either within closed depressions or the edge of a post-glacial lake. As the decaying vegetation encroached laterally into the closed depression or lake, reducing their surface area, it also continued to accumulate vertically upwards to such a degree that, over time, vegetation within the bog changed, becoming less dependent on surface water and/or groundwater and increasingly dependent on rainfall as a source of nutrients. Present day vegetation on a raised bog is totally dependent on rainfall as a nutrient source.

Undisturbed fens are relatively rare in Ireland, most having been drained to facilitate agricultural development in the past. Fens are formed by the growth and decay of vegetation in shallow water environments, principally in poorly drained depressions and adjacent to raised bogs. In contrast to blanket and raised bogs however, vegetation in fens is continuously fed by alkaline groundwater rather than by rainfall.

Bogs and fens are recognised as unique habitats for flora and fauna and many of the remaining undisturbed Irish sites are now legally protected, having been designated Special Areas of Conservation (SAC) or Natural Heritage Areas (NHA) on ecological grounds (refer to NRA *Guidelines for Assessment of Ecological Impacts of National Road Schemes*). The construction of national road schemes in peat environments can present significant environmental challenges, particularly as regards protection of water quality and sensitive ecosystems.

Peat is still valued as an indigenous fuel source, although perhaps less so than in the past. Where national road schemes cross established peat workings, there may be social and economic impacts and these should be considered at all stages of route planning and assessment.

Peat presents unique engineering challenges for national road construction. The poor strength and high compressibility of peat means it is unacceptable as for foundation support and pavement or embankment construction. In light of these limitations, in peat environments, it is necessary to either

(i) excavate and replace the peat with acceptable soil and/or construction materials

(ii) improve the strength and deformation characteristics of the peat foundation

(iii) provide a structural foundation for the road as it crosses over the peat

Where the depth of peat is limited (<5m), it is often excavated and replaced. The disposal and/or recovery of the excavated peat gives rise to significant construction stage impacts (for surface water, noise and traffic) which should be addressed by the Environmental Impact Assessment.

A7 MADE GROUND / LANDFILLS

Made Ground is a term which refers to soil which has been laid down or altered by man. It can comprise natural soils or man-made material (typically waste) or a combination of both. It can be placed in either a controlled or uncontrolled manner. It typically occurs at or around historic or present-day human settlements, at poorly drained agricultural lands, around historic or present day industrial, mining, quarry sites or along infrastructure networks (roads, pipelines etc). Given its uncertain composition and origin, there is a risk that Made Ground may be contaminated, though this can only be conclusively established by site specific ground investigation.

There are numerous historical municipal, industrial and/or commercial landfill sites across Ireland. Most of the older, unlicensed landfills were operated by local authorities or industrial enterprises and located close to town or village settlements or industrial sites. Many of these older landfills were poorly engineered and constructed on peat, poorly drained land or in abandoned quarries. Records of historical landfills can be patchy and unreliable and these sites are often only identified following consultations with landowners or retired local authority staff.

Since the introduction of the *Waste Management Act, 1996* and its associated regulations, operators of waste disposal (landfill) and recovery facilities have been legally obliged to apply for a waste licence from the Environmental Protection Agency or a waste permit from the Local Authority and to operate the waste facility in accordance with the terms of the licence or permit. Notwithstanding this however, a number of unauthorised (illegal) landfill facilities did operate across the country in the late 1990's and early 2000's. In recent years, efforts have been made by the Office of Environmental Enforcement to identify these unauthorised facilities and to compel landowners to remediate them.

A8 KARST

Relatively pure, clean coarse limestone (100% calcium carbonate $CaCO_3$) is prone to dissolution by rainfall. The enlargement (largely by dissolution) of geological discontinuities (joints, fractures, etc.) leads to the formation of a distinctive *karst* landscape which includes landforms such as closed depressions (dolines), sinkholes, springs, turloughs (seasonal lakes which occur in winter and early spring when the groundwater table rises above the land surface) and caves.

Karst is extensively developed in many areas of Ireland which are underlain by limestone bedrock. The word karst is derived from the Serbo-Croat word "krs" and the Slovenian word "kras" meaning stony bare ground. The Kras is a limestone region, now a part of Slovenia and Croatia, in which the distinctive karst landforms (closed depressions, springs, sinks and caves) are exceptionally well developed.

The strict definition of the term karst refers to areas where "surface drainage has been disrupted by underground capture of surface streams by dissolution of the bedrock". A broader definition of the term includes landscapes where the distinctive landforms, both above and below ground, that result from dissolution of the bedrock (and subsequent infill with sediments) are present.

Karstic areas may be currently active (*'active karst'*) or may be decoupled from present day active systems. These decoupled karsts are described as *'palaeokarst'*. It is important to recognise that active karst can be present and karst processes ongoing, even where the limestone bedrock is covered by thick glacial deposits.

In Ireland, much of the pure, clean coarse limestones are karstified, with active karst systems present in many areas, most notably the north-western upland plateau (Sligo, Leitrim and Fermanagh), the Burren in Clare, the western lowlands of Clare, Galway and Mayo, the valleys of Cork, Kerry, Tipperary and Waterford and around the Upper Carboniferous outliers of Kilkenny, Laois and Tipperary. In the east midlands, much of the karst is inactive or "fossil karst".

Karst presents unique engineering challenges, particularly with respect to foundation construction, slope instability and control of drainage. karst areas, locally thick Tertiary or Quaternary age deposits may infill pre-glacial depressions, buried valleys and gorges within the limestone. These features are difficult to identify as they are often hidden beneath glacial deposits or more recent sediments. The increased depth and /or local variation in depth to rockhead associated with such infilled depressions can present significant challenges for the engineering design of heavily loaded bridge foundations. The exposure of localised solution features in rock cutting side slopes for national road schemes give rise to instability and the removal of subsoil cover may, in certain circumstances, induce collapse of loose infilled dissolution features in the cutting floor. Hydrogeological aspects of karst are discussed separately in Section C1.5 of Appendix C1.

An overview of karst in Ireland, its development, its importance and its occurrence, is presented in the GSI publication *'The Karst of Ireland'* (2000).

A9 ECONOMIC GEOLOGY

Ireland has a wide range of mineral and aggregate resources which are at various stages of identification and development. Some deposits have been identified and fully extracted whereas others, which have only recently been discovered, have yet to be developed. At any given time, potential mineral / aggregate resources are under active exploration or evaluation somewhere in Ireland. Resources which are currently considered too small and too complex to develop may become economically viable in future as new exploration and extraction techniques are developed and market demands change. It is conceivable that mineral / aggregate deposits exist and may only be identified at some stage in the future.

'Open File' Mineral Exploration Data

Prior to 2000, geological data obtained from mineral prospecting works for Scheduled Minerals was submitted by exploration companies to the GSI, as required by legislation. However all mineral prospecting data submitted since 2000 has been submitted to the Exploration and Mining Division of the Department of Communications, Marine and Natural Resources. This information has either been submitted in digital format or hardcopy submissions have been scanned. Reports and data held by the Exploration and Mining Division can be downloaded from its website. Data held by the Geological Survey of Ireland (GSI) can be viewed on request or can be downloaded from its website. This 'open file' data includes a wide range of geological data useful for regional and local geology compilation such as

- geological mapping and interpretation
- shallow and deep soil geochemistry
- geophysical surveying
- trenching
- records of a large number of shallow (<50m) and deep (>50m) rotary cored boreholes.

Much of the earlier work (1960's to 1970's) concentrated on soil geochemistry and geophysics, with more detailed geological mapping and interpretation and rotary core drilling from the late 1970's and early 1980's onwards. The quantity of data available for a certain area will depend to a large extent on the prospectivity of that area for Scheduled Mineral deposits. The quality of the data tends to improve through the years, with that filed in the last 15 years generally being of a good to very high standard.

While the basic geological information will be of use in regional and local geology compilation, a review of open file data may also identify minor or undeveloped occurrences of Scheduled Minerals which may be present and soil geochemistry data may indicate areas where elevated levels of metals occur naturally in soil and which may give rise to environmental concerns if excavated or disturbed.

Metalliferrous and Industrial Minerals

In Ireland at present, there are three base-metal (zinc, lead and silver) mines operating at Navan Co. Meath, Lisheen Co. Tipperary and Galmoy Co. Kilkenny. Metalliferrous minerals were previously worked at various locations, including Avoca Co. Wicklow, Silvermines Co. Tipperary, Tynagh Co. Galway and Ballysadare Co. Sligo. Copper, silver and mercury has also been mined at Gortdrum, Co. Tipperary. Numerous other historical small-scale mine are located around the country, though there is little surviving surface evidence of these workings eg. the coal mines of the Castlecomer plateau (Kilkenny / Laois) and Arigna in Roscommon. Production of gypsum and salt is currently taking place from underground workings in Kingscourt Co. Cavan and Carrickfergus Co. Antrim, respectively. In general, national road schemes should avoid sterilising known mineral reserves which are currently being exploited or could potentially be at some point in the future.

Construction Aggregates

Approximately 130 million tonnes of construction aggregates are produced annually from existing pits and quarries by the quarry, concrete and asphalt industries. The protection and sustainable development and use of these natural resources and the continued supply of these materials into the future is a key requirement of the building and civil engineering industries. The Geological Survey of Ireland (GSI) published the 3rd edition of its *'Directory of Active Quarries, Pits and Mines'* in 2001. The *Concrete Products Directory* (3rd edition, 2005) published by the Irish Concrete Federation (ICF) is a further source of information on the quarrying and concrete products sector. However, as not all active pits or quarries are identified in either the GSI or ICF publication, it is necessary to contact Local Authority planning departments to obtain a definitive list of pits and quarries registered with them under Section 261 of the Planning and Development Act (2000) and others which have obtained planning permission since 28 April 1999. As for minerals, national road schemes should generally avoid sterilising known aggregate reserves which are currently being exploited or could potentially be at some point in the future.

A10 GEOLOGICAL HERITAGE

Geological heritage encompasses the earth science component of nature conservation. This includes both bedrock and unconsolidated (soil) deposits close to the surface and the past and present processes that shape the land surface we inhabit. A broad definition also includes the geological influences upon, and interaction with, human culture. Mining, quarrying and other mineral exploitation constitute a part of our geological heritage, but the influence of geology on settlement patterns and land use is often unappreciated.

Geological heritage can be defined in numerous ways as:

(i) the geological variety of rocks, minerals, fossils and landscape together with the natural processes that form them;

(ii) the link between landscape, peoples and their culture;

(iii) the variety of geological environments, phenomena and processes that make the landscape and soils which provide the framework for life on Earth

The identification of geological heritage is achieved by finding sites or areas that best demonstrate particular types of geology, processes or phenomena that rank as noteworthy. The site selection process is currently being undertaken by the Geological Survey of Ireland (GSI), through the Irish Geological Heritage (IGH) Programme (Parkes and Morris 2001). Geological heritage is assessed under 16 different *'themes'* listed below, though sites are frequently of importance in more than one theme. Peatlands are effectively covered by their designation as Special Areas of Conservation (SAC) and are not therefore included in the IGH Themes.

IGH 1 Karst
IGH 2 Precambrian to Devonian Palaeontology
IGH 3 Carboniferous to Pliocene Palaeontology
IGH 4 Cambrian–Silurian

IGH 5 Precambrian
IGH 6 Mineralogy
IGH 7 Quaternary
IGH 8 Lower Carboniferous
IGH 9 Upper Carboniferous and Permian
IGH 10 Devonian
IGH 11 Igneous Intrusions
IGH 12 Mesozoic and Cenozoic
IGH 13 Coastal Geomorphology
IGH 14 Fluvial and Lacustrine Geomorphology
IGH 15 Economic Geology
IGH 16 Hydrogeology

The IGH Programme operates a two-tier site designation. The primary national site designation is **Natural Heritage Area (NHA),** which is the responsibility of the National Parks and Wildlife Service (NPWS), currently part of the Department of the Environment, Heritage and Local Government (DoEHLG). The IGH Programme is working in partnership with NPWS to complete the spectrum of nature conservation sites, by integrating geological heritage sites with other proposed NHAs protected by the Wildlife (Amendment) Act 2000.

The second designation, introduced by the National Heritage Plan (2002) is that of **County Geological Site (CGS).** It will form a major strand of geological nature conservation to complement the various ecological and cultural conservation measures. While a County Geological Site is not statutorily protected, the designation is intended to provide recognition for the site and a measure of protection through incorporation into the County Development Plan (CDP). Many Local Authorities have now published a list of County Geological Sites within their development plans, while others are seeking GSI advice. As listed sites may change through time, local authority planning departments will need to be consulted to obtain a definitive list of sites. Some sites listed first as CGS may, after due consultation and assessment, be proposed as NHAs.

The size of designated sites varies upwards from tiny rock exposures with unusual minerals to large landscape areas showing massive landforms produced by glaciation, coastal erosion or other processes. In some themes, the scale of some landforms is so great that patterns are essentially only visible from space with satellite imagery. For example in IGH7 – Quaternary Theme, some of the drumlin fields and glacial moraine features, characteristic of the northern midland counties, are too big for meaningful designation as an NHA. Most large area geological sites occur in protected sites such as National Parks or SACs.

Amongst the more prominent examples of geological heritage in Ireland are the limestone pavement of the Burren in Clare, the 25km coastline and former mine workings of the Copper Coast Geopark in Waterford and Mitchelstown Cave in Cork.

The impact of national road construction on geological heritage sites is different to that for natural or cultural heritage sites in that impacts are just as likely to be positive as negative. The nature of any impact will largely depend on the heritage theme and the alignment of the proposed road scheme.

A11 GEOHAZARDS

Geohazards (or geological hazards) involve the interaction between people and the environment and the ongoing physical processes of the Earth. In Ireland, the principal geohazards include subsidence, slope instability and landslides, soft / compressible ground, fluvial and coastal erosion, deposition and flooding.

Subsidence may be induced by ground movement or collapse into natural cavities in karst environments or man-made cavities, such as disused mines. Beese and Creed (1995) reviewed the occurrence of subsidence sinkholes in karst environments around Cork and found that many were re-activated by construction works which modified pre-existing surface water and groundwater flow regimes. More generally, Ford and Williams (1989) estimated that engineering and environmental problems in karst regions incur a global cost of thousands of millions of dollars annually (at 1980's prices). An overview of the engineering and environmental aspects of karst is presented in the GSI publication *'Karst in Ireland'*(2000).

Slope instability can occur as a gradual process, as with soil creep. Alternatively, it can be catastrophic, and occur as a major landslide, bogslide or flow. Until relatively recently, Ireland had been regarded as a relatively benign environment for landslides. However two widely publicised events in Autumn 2003, at Pollatomish in Co. Mayo and Derrybrien, Co. Galway, highlighted the damage and upheaval associated with a major landslide event. Although the Irish Landslides Database maintained by the GSI records over 100 historic landslide events, a recent pilot study undertaken by GSI in an upland area suggested that there has been significant under-recording of such events in Ireland. On the basis of this pilot study, GSI identified a need to prepare landslide susceptibility maps to better inform planning decisions and mitigate future property loss and loss of life. The most up to date review of landslide events in Ireland is presented in the publication *'Landslides in Ireland',* by the Irish Landslide Working Group and GSI in 2006.

Soft, loose or compressible ground such as peat, calcareous marl, lacustrine or estuarine silts and clays and windblown sands present risks of instability and/or excessive settlement.

Fluvial erosion, sediment deposition or flooding also present significant risks and are generally associated with construction or development in close proximity to rivers or river floodplains.

With the exception of flooding, geohazards tend to be relatively rare in Ireland. They nonetheless need to be considered at preliminary stages of road planning to avoid risks to construction personnel and prospective road users.

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APPENDIX B : HYDROLOGY, THE IRISH HYDROLOGICAL ENVIRONMENT

B1 Climate, Rainfall and Evapotranspiration

Ireland's climate is of the cool temperate oceanic type, being mild and moist, windy and changeable. There is an almost even distribution of rainfall through the year, with an average monthly precipitation of at least 50mm is this low even in the driest period from March to June.

Generally in Ireland there is an increase in rainfall amount from east to west. Most of the lowland area in the eastern half of the country has between 750mm and 1000mm of rainfall per year whereas annual rainfall in the lowland areas in westen half generally averages between 1000mm and 1250mm. In the mountainous areas of Kerry, Mayo and Donegal rainfall exceeds 2000mm per year. The mean annual rainfall for the period 1961-1990 is shown in Figure B-1 (Met Eireann). Variations in monthly rainfall in any month can range from almost zero to greater than 200mm.

Figure B-1: *Mean Annual Rainfall in Ireland (1961-1990) from AGMET - Agroclimatic Atlas of Ireland - in turn sourced from Met Eireann.*

Although rainfall in Ireland can be quite variable from year to year, the annual amount in any area is generally within ±25% of the long-term average. There also tends to be longer-term trends in different areas where rainfall is well above or below the average amount for periods of up to 10 years.

The 60-minute and 2-day rainfall amounts with a return period of 5 years have been published in map form. These values can be used to calculate rainfall amounts for other durations and return periods. The 60-minute and 2-day rainfall amounts with a return period of 5 years typically range from 16mm to 18mm and from 60mm to 100mm, respectively (Collins and Cummins, AGMET, 1996).

The potential surface runoff (expressed in m^3/ha) generated by rainfall events of these intensities and durations can be estimated for the relevant catchment areas. Over the last 10 years there have been a significant number of instances of 2-day rainfall amounts of up to and exceeding 100mm at various locations in Ireland. This is generally close to the 1 in 25-year rainfall event.

The average number of rain-days varies from around less than 200 in the south-east to over 250 in the south-west, west and north-west.

Potential evapotranspiration (PE) in Ireland varies with the season; the average PE for the winter period October – March is less than 125mm, while the average PE for summer months (April – September inclusive) ranges from 350mm to 475mm. The geographical distribution of PE shows a strong coastal-inland trend, especially in the winter months where the aerodynamic part of the process is favoured by the greater windiness of the coastal areas. Along the coastal margins of Ireland, PE is 500-550mm/annum, while inland it drops to less than 450mm/annum over much of the northern part of the island.

The largest areal change in evapotranspiration occurs with altitude. A 3mm reduction in the monthly PE can generally be assumed during the growing season (March – September) for each 100m increase in altitude (Keane, 1986). Average daily PE generally varies from 0.5mm in December and January to 3mm or more in the period May to July (Holden, 2001, AGMET, 2001).

During the growing season, March to September, the increased transpiration demands on the soil/water balance from vegetation can exceed the readily available water (RAW) and cause the actual evapotranspiration (AE) to be reduced below its potential amount (Allen *et al*., 1997). Eventually, if the demand on soil-water reaches the total available water (TAW), then evapotranspiration will be reduced to zero. The long-term AE is far greater in the April to October period when the temperature is higher, the days are longer and plant growth rates are high, than the October – March period when the opposite is the case. In Ireland the average annual ratio of AE/PE tends to be between 90-95%; refer to Figure B-2 below.

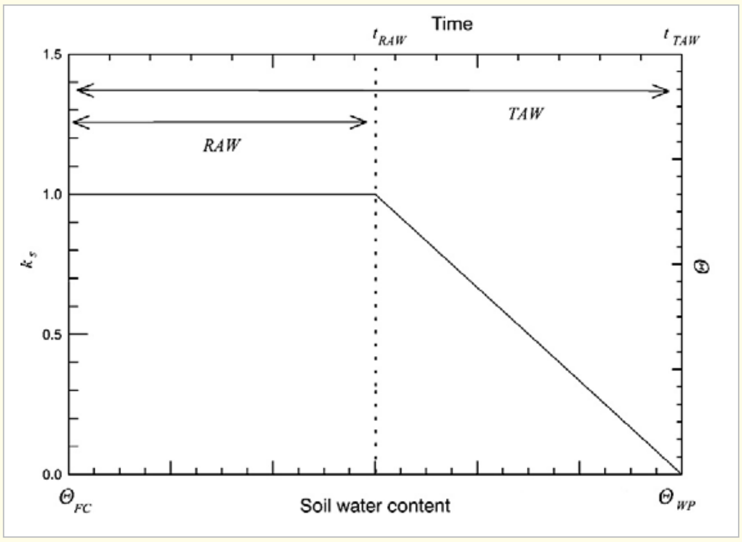

Figure B-2: *Soil Water Content for RAW and TAW (FAO, 1997)* where k_s =AE / PE ratio, θ_{FC} = Field Capacity and θ_{WP} = Wilting Point

The amount of water a soil is able to hold is referred to as soil moisture. Like PE, soil moisture also varies throughout the year, being at field capacity for most of the winter months on all soils and reaching a soil moisture deficit of up to 100mm in some soils in some summers. A significant deficit does not occur in all areas, or in all soils, every year with any regularity.

By estimating the amount of actual evapotranspiration, the amount of water available for recharge and runoff can be estimated. This amount of water available for recharge and runoff is often referred to as effective rainfall.

B2 Climate Change

Climate is defined as 'the average weather experienced in a region over a long period'. In Ireland, the reference period is taken as 30 years, the most recent of which is 1961-1990. It is now acknowledged by almost all climate scientists (IPCC, 2007) that the Earth's climate is currently changing in response to human activities, principally the emission of greenhouse gases (carbon dioxide). It is expected that Ireland will experience significant changes in rainfall characteristics over the next 100 years as a result of such climate change.

The first and most detailed analysis (to date) of future Irish climatic conditions, titled '*Climate Change: Regional Climate Model Predictions for Ireland*' (McGrath *et al*, 2005) was published by the Environmental Protection Agency in 2005. The current prediction for Ireland is for a more uneven distribution of rainfall through the year with

(i) warmer and generally drier summers, particularly in the south and east, which implies that watercourses are likely to become drier in summer and that values for the dry weather flow (DWF) of rivers and streams are likely to decrease

(ii) wetter winter periods, particularly in the north and west, with more frequent and intense winter storms, which implies that peak river flows in watercourses and flood risk are likely to increase.

These changes, and specifically the implications for the design of drainage systems on national road schemes, need to be considered by road design teams, and sufficiently robust environmental and engineering drainage solutions developed to deal with future river flows.

Although rainfall events are predicted to become heavier, there is considerable uncertainty in quantifying these predictions and by extension, the resultant impacts on peak and low river flows. For peak river flows, a pragmatic approach adopted by the Greater Dublin Strategic Drainage Study and the UK Highways Agency publication 'Road Drainage and the Water Environment' (HA216/06) is to test the sensitivity of the drainage design to a factored increase on present day rainfall depths for all durations and return periods and where necessary, make provision for this in drainage design. The Greater Dublin Strategic Drainage Study recommends a factored increase of 10% (to 2080), whereas HA216/06 recommends 20% (over 50 years).

For low flows, the Greater Dublin Strategic Drainage Study recommends that the number of summer rainfall events be reduced by 40% and that summer rainfall intensities be factored by 0.9 (ie. reduced by 10%) for all but the top 5 rainfall events.

Climate change is also predicted to result in sea level rise and increased risk of coastal flooding. The Greater Dublin Strategic Drainage Study recommends that drainage designers should assume a sea level rise of between 400mm and 480mm for coastal areas around Dublin by 2080 whereas HA216/06 advises designers to assume between 4mm and 6mm rise in sea level per year for various UK regions. It should also be recognised that higher sea levels will lead in turn to higher water levels upstream in river estuaries.

Given the variability in the predicted impacts of climate change across the country and the variability in hydraulic characteristics of drainage catchments, it is not feasible to provide universally applicable guidance as to how climate change impacts should be quantified. In the short-term, it is expected that drainage engineers will need to exercise professional judgement in assessing such impacts and developing appropriate design responses. In the medium-to-longer term, as the implications of climate change become clearer and further research is undertaken, it is expected that guidelines for assessment of climate change impacts and development of engineering responses will be issued (and continually updated) and applied to the design of drainage systems for national road schemes.

B3 Surface Water Systems

Fluvial action by streams and rivers, the essential features of surface water systems, create valleys, the fundamental landform of most parts of the earth's surface. Many streams and rivers and parts of their adjoining flood plains are important natural habitats.

Streams and rivers are active agents of erosion, material transport and deposition. A river's energy (erosive or carrying power) is largely determined by the volume of water it contains and the gradient or slope of its course. The erosive power of rivers is mainly a function of the material they carry. Rivers are either continually trying to erode their streambed or cut into their banks and create meanders.

Streams and rivers also deposit material carried in suspension when the velocity drops, as for example where a steep mountain stream flows into the western side of Lough Tay at Luggala in County Wicklow and creates an alluvial fan, or the 'birds foot' delta created at the mouth of the River Liffey in Dublin.

The character of a river varies with the type of ground through which it flows and changes at various stages during its journey from source to sea. Headwater streams in upland areas tend to be short and steep with rapid flows. Rapids and waterfalls are common, streambeds are littered with cobble and boulder sized rocks and water quality is good. At this stage streams typically flow along steep sided V-shaped gorges and valleys, for example the headwaters of the River Barrow in Slieve Bloom. Near the end of its course, a river typically moves slowly and meanders across flat plains. The banks tend to be lower and rivers overflow in response to heavy rainfall.

Over time, rivers or certain stretches can change their character in response to geological conditions, processes and events and changing climatic conditions. For example a number of the main rivers in the east and south-east, rise in the Central Plain of Ireland but flow out through rejuvenated gorges, e.g. the River Boyne at Beauparc, County Meath.

The drainage patterns of river systems reflect a wide range of influences including morphology, geological structure, climate and the history of drainage development. It is not surprising, therefore, to find great variability and many individual types of drainage pattern. In Ireland examples of the more common drainage patterns are found in the River Barrow (dendritic), the headwaters of the Barrow, Brosna and Nore (radial) and the ridge (anticlinal) and valley (synclinal) province of the south of Ireland (trellised).

The drainage systems of Irish rivers are quite variable and range from the 'fine textured', close network of streams in the rocky, wet and boggy watersheds of Connemara to the more widely spaced 'coarse textured' stream network of the Clare River in County Galway where much of the drainage is underground in the karstified limestones.

Catchment Areas

For administrative and other reasons the island of Ireland has been divided up into 40 hydrometric areas. Each area comprises a single large river catchment (with the exception of the River Shannon which is divided in two) or a group of smaller ones and neighbouring coastal areas.

In order to carry out its programme of work, the Water Resources Division of An Foras Forbartha (AFF) divided the 26 counties of Ireland into 7 Water Resource Regions in 1971. These regions comprise groups of major river catchments and were based on the notion that the water requirements of each region could be supplied from available resources within each region. Under the EU Water Framework Directive, 8 River Basin Districts (RBDs) have been established throughout the island of Ireland. Four of the RBDs are located entirely within the Republic of Ireland (South-Eastern, Eastern, Western and South-Western), three are Cross-Border / International (Shannon, North-Western and Neagh-Bann) and one is entirely within Northern Ireland (North-Eastern). The boundaries and the names of the River Basin Districts are largely based on the former AFF Water Resource Regions.

The catchment size of the hydrometric areas varies between 50km^2 and 7,000km^2. Most of the larger catchments have a variety of geological and topographical conditions and the surface water flow regimes are therefore complex. Table B-1 shows runoff characteristics of typical river catchments in various parts of the country.

River	Gauging Station	Catchment Area (km^2)	Average Rainfall 1961-1990 (mm/yr)	Average Run-off (m^3/s)	Specific Run-off ($l/s/km^2$)	Low-flow Runoff (m^3/s)	Specific Low-flow ($l/s/km^2$)
Boyne	Navan	1610	898	24.19	15.0	1.4	0.87
Nore	Durrow	491		6.63	13.5	0.7	1.43
Blackwater*	Ballyduff	2338	1159	58.56	25.1	10.65	4.55
Shannon	Athlone	4703					
Suck	Bellagill	1184	1050	22.64	19.1	1.4	1.18
Brosna	Ferbane	1207	931	17.31	14.34	3.91	3.24
Moy	Foxford	1737	1270	56.93	32.8	7.59	4.37

**Munster Blackwater*

Table B-1: *Run-off Characteristics of Typical River Catchments. An Foras Forbartha (1970s). Mac Carthaigh, M. (1995).*

In the south of Ireland, specific run-off based on the dry weather flow (DWF) is of the order of 1.0 $l/s/km^2$ whereas in the east of the country, it is closer to 0.5 $l/s/km^2$.

Flow Rates

In simple terms, river flow is composed of surface run-off from precipitation and baseflow from groundwater storage. Some rivers (e.g. River Suir) have a very high baseflow, while other rivers have a low baseflow, a reflection of the geology of their respective catchments.

Rivers can exhibit a large variation in flow rate. There are average flows, peak flows and low flows. Two commonly used measures for reporting low flow are the '95-percentile flow' and the 'dry weather flow' (DWF). There is also the N-day sustained low flow, e.g. the '7-day sustained low flow'.

The water budget approach can be used to estimate the average annual potential run-off from a catchment. This is obtained by subtracting the average annual actual evapotranspiration (AE) from the average annual rainfall and multiplying the result by the catchment area.

In road schemes estimates of flood flows are required wherever significant watercourse crossings are proposed. For an ungauged catchment, or for catchments where there is less than one year's flow data, the approach outlined in the Flood Studies Report (FSR, 1975) has been shown to give a good first approximation of flood flows. The FSR produced flood frequency growth curves for various regions in the UK and one for Ireland.

The mean annual maximum flow (sometimes known as Q_{bar}) for a catchment can be estimated by a number of methods. The calculated Q_{bar} is multiplied by the national flood frequency growth factor for Ireland to yield the required return period flood estimate. Two flood frequency methods for estimating Q_{bar} are outlined in Appendix B2.

For gauged catchments, flow data is available from the Office of Public Works (OPW), Environmental Protection Agency (EPA), Electricity Supply Board (ESB) or Local Authorities. The Register of Hydrometric Gauging Stations in Ireland (EPA, 2000) gives a list of all flow gauging stations in the country, including their grid reference. The numbering system for hydrometric stations is based on the hydrometric area number.

A statistical analysis of river flows has been published for each of the water resource regions (An Foras Forbartha / Environmental Research Unit, 1980's). These publications give details of the magnitude and frequency of occurrence of river flows based on records from gauging stations operated by various organisations, such as OPW and ESB. These publications tend to concentrate on low flows, as their principal applications are in connection with water supply and/or pollution control.

A summary of hydrometric records has been published for some of the water resource regions (An Foras Forbatha, 1970's). These publications contain details of gauging installations in the particular region together with the results of actual / calibration flow measurements performed at the gauging stations.

Flooding

Historically, flooding has been a major concern in Ireland for the past two centuries. The Arterial Drainage Act of 1945 sought to relieve flooding and improve agricultural land. This act was amended in 1995, when the emphasis changed to the protection of urban areas subject to flooding.

Recent extreme flood events in Ireland include those associated with Hurricane Charlie in 1986, the East Coast tidal floods of February 2002 and flooding of the River Tolka in November 2002. Examples of extreme events and their approximate return periods are given in Table B-2 below.

Event	Return Period
Hurricane Charlie 1986	>100 years
River Tolka November 2002	~100 years
Slaney 2000	~37 years
Suir (Clonmel) 1995 - 2000	~5 to ~25 years

(Source: Final Report of the Flood Policy Review Group, OPW 2003)

Table B-2: *Recent Flood Events and Approximate Return Period*

Some places which are historically associated with flooding are Gort in County Galway, Kilkenny City, Clonmel and Carrick-on-Suir, both in County Tipperary. Flooding in the Gort area, which lies on karstified limestone lowlands, is related to a rise in the water table level, whereas in Kilkenny it is mainly due to the low permeability and steeply sloping nature of the local River Dinan catchment a relatively short distance upstream of the city (An Foras Forbatha, 1987). Flood warning schemes are in place in Kilkenny City and on the Lee Estuary in Cork City.

Flood relief schemes that have been completed by the OPW under the 1995 Arterial Drainage (Amendment) Act are: Cappamore, Co. Limerick; Sixmilebridge, Co. Clare; Duleek, Co. Meath; Carrick-on- Suir, Co. Tipperary; Dunmanway, Co. Cork and Kilkenny City.

B4 Surface Water Quality

The water quality of rivers and lakes has been monitored in Ireland since 1971. The monitoring programme is based on a 3-year cycle. At present, the EPA prepares a report every three years on the quality of water in rivers, lakes, estuaries and groundwater, the most recent of which is for the period 2001 – 2003. The principal source of the data on which the report is based is survey work undertaken by the EPA itself and by Local Authorities.

Rivers

The chemistry and quality of river waters is generally a reflection of catchment geology and landuse. In the 1970s, water quality in many river stretches was poor due to uncontrolled industrial, municipal and agricultural discharges. Water quality improved in the 1980s, following the introduction of the Local Government (Water Pollution) Act of 1977 and considerable investment in wastewater treatment plants. The most recent EPA report shows that there has been a 32% decrease in the lengths of seriously polluted river channels, compared with the previous 1998 - 2000 review period.

In general, the less densely populated and less developed regions in the west, south-west and north-west of Ireland have longer stretches of unpolluted river channel, while the eastern and south-eastern areas are most affected by water quality degradation. Locally, there is good river quality in largely undeveloped areas and often poorer river quality downstream of urban centres and industrial developments. The main sources of pollution are effluent discharges from municipal wastewater treatment plants, industrial effluent discharges and diffuse agricultural and urban runoff.

Important river water quality parameters include Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Total Oxidised Nitrogen and Orthophosphate. These parameters, which are used by the EPA to classify *river* water quality, are described in Appendix B3. The main effects of organic pollution on the quality of river water are a reduction in dissolved oxygen (deoxygenation) and nutrient enrichment (eutrophication).

Lakes

The key physical parameters affecting water quality in lakes are wind movements, temperature changes and inflows / outflows. In summer there are reduced inflows, increased solar radiation with corresponding elevated water temperature and reduced dissolved oxygen values.

If lakes are deeper than 10m, they may be thermally stratified and a thermocline (the depth zone where the temperature falls off rapidly with depth) may develop. The top of a thermocline usually varies between 5m and 25m below the surface. The stagnant layer of water beneath the thermocline is referred to as the *hypolimnion*. The mixed surface layer of water above the thermocline is referred to as the *epilimnion*.

In temperate latitudes most lakes are warm in summer and cool in winter. As autumn progresses the epilimnion cools more rapidly than the lower waters until a time is reached when the upper waters are denser than the lower waters. There is an immediate upsurge known as autumn turnover when the whole body of water gets thoroughly mixed.

The main concerns regarding lake water quality in Ireland are eutrophication and acidification. The key parameters used by the EPA to classify *lake* water quality are transparency, chlorophyll and phosphorus. These parameters are also described in Appendix B3.

Water Quality Assessment Systems

Water quality assessment of surface waters in Ireland is based on data collected from physico-chemical and biological surveys. Assessment involves taking river water samples for analysis and the examination of samples of sediment from the bed of the river or stream. River water samples are generally analysed for up to 12 parameters. While the test parameters will vary dependant on the relevant water quality standards (drinking, bathing, salmonid), they will typically include

- Temperature
- pH value
- Conductivity
- Dissolved Oxygen
- Biochemical Oxygen Demand
- Ammonical Nitrogen
- Suspended Solids
- Nitrate
- Orthophosphate
- Total Hardness
- Zinc (total)
- Copper (dissolved)
- Petroleum Hydrocarbons

The biological monitoring of rivers is based on the relationship between water quality and the relative abundance and composition of the macro-invertebrate communities in the sediment of rivers and streams. The greater the diversity, the better the water quality. The biological information is condensed to a 5-point numerical scale (Biotic Index or 'Q' value), an arbitrary system in which community composition and water quality are related. Further details of the assessment system are provided in Appendix B3.

A similar water quality system (the General Quality Assessment system) is used in the classification of river waters in Northern Ireland. Some details of this system are also provided in Appendix B3.

Lake water quality in the Republic of Ireland is assessed by reference to a scheme proposed by the OECD in 1982. The traditional trophic categories are described in this scheme by establishing limits for the three key indicator parameters, total phosphorus, chlorophyll and water transparency in assessing the level of eutrophication. As insufficient data does not allow calculation of mean annual values of the parameters, a modified version of the scheme is used in which the classifications are based on the annual maximum chlorophyll concentration (refer to Appendix B2).

Impacts

Construction of road crossings (culverts / river underbridges) or discharges to watercourses give rise to a number of potential impacts on water quality and fisheries, the most notable of which are the increased pollution risk from surface run-off during construction, accidental spillage of fuel and discharge of road run-off drainage.

It is estimated that increasing traffic densities and higher proportions of heavy goods vehicles (HGVs) are likely to lead to an increased risk of accidents that could give rise to hazardous spills. Proximity to junctions and roundabouts also increases the risk of accidents. In the event of an accident resulting in a spill on the carriageway, the time required for the emergency services to arrive at the scene is also a factor in the assessing the risk. A formula used to calculate the risk of serious accidental spillage leading to pollution is presented and discussed in Appendix B4.

Re-sectioning or re-aligning river channels can affect the geomorphological processes which control river habitats and can therefore have indirect impacts on water quality and fisheries upstream or downstream of the affected section of channel. Guidance on bridge and culvert design and construction is provided in the NRA publication *Guidelines for the Crossing of Watercourses during the Construction of National Road Schemes*.

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APPENDIX B2: HYDROLOGICAL ASSESSMENT OF DESIGN FLOODS

There are a number of methodologies available for estimating flood flows for various return periods. In the UK the Flood Estimation Handbook (FEH) published by the Institute of Hydrology in 1999 has superseded the 1975 Flood Studies Report. The FEH has become the standard method in the UK.

A revised Flood Studies Report, similar to the UK FEH, but specifically for the Republic of Ireland has been proposed. The Joint National Committee of the Hydrological Programme and of the International Commission on Irrigation and Drainage passed a recommendation that a review and update of the FSR methodologies should be undertaken in Ireland (*Final Report of the Flood Policy Review Group*, OPW 2003).

The two flood frequency methods recommended for use in the estimation of flood flows for national road design is as follows:

1. The 1975 Flood Studies Report (FSR) catchment characteristic method

2. The Institute of Hydrology Report No. 124 method (generally for catchments less than $2km^2$).

B2.1 FLOOD STUDIES REPORT 1975

Where there is less than one year's flow data for a catchment the approach outlined in the Flood Studies Report (FSR) has been shown to give a good first approximation of flood flows.

A multi-variable equation was developed for the mean annual maximum flood Q_{bar} for each region of Great Britain and Ireland. The six-variable equation that was derived for Ireland for Q_{bar} (Cawley, 2003) is as follows:

$$Q_{bar} = 0.00042\ AREA^{0.95}\ Fs^{0.22}\ SOIL^{1.18}\ SAAR^{1.05}\ S1085^{0.16}\ (1 + LAKE)^{-0.93}$$

where

AREA is the catchment area in km^2

Fs is the number of stream junctions as shown on the 1:25,000 map, divided by the catchment area in km^2

SOIL is the soil index (refer to Table B-3).

SAAR is the average annual rainfall in mm.

S1085 is the slope of the main stream between points 10% and 85% along its length in m per km.

LAKE is the fraction of the catchment draining through a lake or reservoir

A three-variable FSR equation with a greater margin of error has also been produced for Q_{bar}, which can be used to give an estimation of the mean annual maximum flood.

$$Q_{bar} = 4.53 \times 10^{-7}\ AREA^{0.84}\ Fs^{0.51}\ SAAR^{1.34}$$

This may be useful where it is difficult to evaluate some of the parameters in the six-variable equation. Supplementary reports to the FSR produced similar 3- and 4-variable equations.

B2.2 INSTITUTE OF HYDROLOGY REPORT NO. 124

In 1994, as a refinement of the Flood Studies Report (FSR, 1975) the Institute of Hydrology carried out regression studies on 71 small catchments (mainly in the UK but also presumably some in Ireland) of less than $25km^2$ in area. Many of the catchments were rural with small urban fractions. The study arbitrarily selected only those catchments for which the proportion of urban area to rural was less than 0.025. The following three-parameter equation was derived by regression analysis:

$$Q_{bar} = 0.00108\ AREA^{0.89}\ SAAR^{1.17}\ SOIL^{2.17}$$

where Q_{bar} is the mean annual peak flow in m^3/s

AREA is the catchment area in km^2

SAAR is the average annual rainfall for the catchment

SOIL is a soil index with values ranging from 0.15 – 0.5 (Table B-3)

Cawley and Cunnane of NUI Galway presented research into the accuracy of the IH124 equation in predicting peak runoff from small catchments in a paper at the National Hydrology Seminar 2003. The research showed that the following equation produced a marginally lower percentage error between the observed and computed mean annual peak flow (Q_{bar}) than the IH 124 equation and was more accurate in 41 out of the 71 catchments:

$$Q_{bar} = 3.6 \times 10^{-5}\ AREA^{0.94}\ SAAR^{1.58}\ SOIL^{1.85}$$

However, they showed that significant differences exist between the above equation and the IH 124 equation when applied to small catchments (i.e. $<1km^2$) and to the higher soil classes (i.e. Class 2 and higher) of increasingly poor drainage.

The equation from the Institute of Hydrology Report No. 124 for the predicted mean annual maximum runoff from small catchments ($<2km^2$) is often used for design of drainage systems on proposed development sites in Ireland.

Soil Class	WRAP*	Soil Index
Class 1	Very high	0.15
Class 2	High	0.3
Class 3	Moderate	0.4
Class 4	Low	0.45
Class 5	Very low	0.5

** winter rainfall acceptance potential*

Table B-3: *Indices of Likely Run-off from Different Soil Categories (FSR, 1975)*

The concept of the flood frequency growth curve as derived in the flood studies report is applied to the estimate of the average peak annual flow as obtained from the IH 124 method.

B2.3 FLOOD FREQUENCY GROWTH CURVE

The statistical flood estimation procedures are largely based on the index flood method:

$$Q_T = Q_{index} \text{ x } X_T$$

where

Q_T is the expected flood for the T year return period

Q_{index} is the baseline flood (e.g. the mean annual maximum flood, Q_{bar})

X_T is a growth factor for the T-year return period

The FSR (1975) derived a flood frequency growth curve for Ireland from statistical analysis of 112 Irish catchments having an average of 15 record years per station. The equation for the growth curve is:

$$X_T = Q_T / Q_{bar} = -3.33 + 4.2\exp(0.05Y_T)$$

where

$Y_T = -\ln(-\ln(1-1/T))$ (i.e. Y_T is an index related to the return period)

The design flood magnitude for a given return period can be estimated by multiplying the Index Flood Q_{bar} (mean annual maximum flood) by the T-year return period growth factor (X_T).

Return period (yrs)	2	5	10	25	50	100	200
Growth factor*	0.96	1.2	1.35	1.55	1.7	1.84	1.99
Q_T (m^3/s)							

**Revised National Flood Frequency Growth Factor for Ireland (Cawley, 2003)*

Table B-4: *Calculation of Natural Run-off from a Given Catchment for Various Return Periods*

B2.4 REFERENCES

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APPENDIX B3 : WATER QUALITY PARAMETERS AND QUALITY ASSESSMENT SYSTEMS

B3.1 RIVER WATER QUALITY PARAMETERS

Biochemical Oxygen Demand (BOD)

Any organic waste matter entering a river/lake acts as a food source for the micro-organisms living in the water. These micro-organisms use the dissolved oxygen present in the water to break down the food. The amount of oxygen used up by the micro-organisms is measured using the BOD test and provides a measure of whether the water is clean or polluted. The test is carried out under standard conditions for 5 days at $20^{o}C$ in the dark. Unpolluted river waters are likely to have a BOD value of <3mg/l O_2 and values significantly above 4-5 mg/l indicate possible pollution. High flows or floods can also affect the BOD value in rivers.

Dissolved Oxygen

Dissolved Oxygen is the amount of oxygen in the water. Oxygen is essential for the survival of fish and other aquatic life and the DO test is one of the most important indicators of pollution in rivers. Normally water is 100% saturated with oxygen but if the oxygen is used up, either by polluting material or by plants that live in the water, the oxygen levels can decrease. If the levels fall too low a fish kill can result.

Phosphorus

Phosphorus occurs widely in nature, in plants, micro-organisms and human and animal wastes. The phosphorus content of effluent discharges is generally reported as Total Phosphorus (mg/l P). In the case of river waters the phosphorus content is usually reported as ortho-phosphate (mg/l P or possibly as PO_4).

Bioassay studies have shown that about 20% of the total phosphorus is available for plant growth in unpolluted streams. A survey along the main channel of the River Boyne has indicated that approximately 30%-60% of the total phosphorus is available as orthophosphate (Boyne Water Quality Management Plan, 1991).

Orthophosphate is a biologically active element and is freely removed from water by plants and algae especially during the spring-autumn period (Neill, 2001). It is the phosphorus species primarily responsible for eutrophication.

The analytical results reported for river samples give the orthophosphate concentration of the water. However, in the spring-autumn period some orthophosphate will be bound up in weeds and algae (depending on the amount present) and possibly in river sediment. Hence, the reported values in the spring-autumn period will be minimum values. It is reported (Neill, 2001) that in Ireland where the rivers are short that surface waters may reach the sea/estuaries before all organic phosphate can be converted to orthophosphate.

The Phosphorus Regulations (1998) require that river water samples be analysed for molybdate-reactive phosphorus (MRP). Molybdate-reactive phosphorus is mainly orthophosphate; however it may also contain very small amounts of other forms of P. MRP is a measure of the phosphorus form most readily available for uptake by rooted plants and algae in freshwaters. In unenriched waters the annual median concentrations are likely to be < 0.025mg/l P.

The Phosphorus Regulations apply to average river flows. The standards set in the Phosphorus Regulations are based on a well-established relationship between ecological quality in Irish rivers and phosphate levels. Repeated examination of over 1,000 sites in the period 1983 to 1994 revealed a strong statistical relationship between the biological Q rating (used by the EPA) and molybdate-reactive phosphorus (MRP) in Irish rivers.

Of the principal nutrients in plants phosphorus is the most amenable to control. Under normal conditions phosphorus is only sparingly available from natural sources and it is arguably less easily leached from soil than nitrate.

Oxidised Nitrogen

Oxidised Nitrogen is the combination of nitrate and nitrite. Most of the nitrate found in surface waters either directly comes from waste discharges or from runoff from land treated with fertilizers. Nitrate levels in river waters vary on an annual basis and are generally lowest in July/August and highest in January/February (when the river flows are normally also higher).

Nitrite levels in unpolluted waters should be low (<0.05mg/l N). It is an intermediate in the oxidation of ammonia to nitrate and because many effluents, including sewage, are rich in ammonia high levels of nitrite in river waters may indicate recent pollution.

B3.2 LAKE WATER QUALITY PARAMETERS

Water Transparency

Transparency is a water quality characteristic of lakes and reservoirs. Transparency is measured using a suspended a Secchi disk which is a white circular plate of 20 to 30cm or larger in diameter and made of rigid plastic or metal. The transparency is the depth at which the disc disappears from view.

Water Transparency is an important aesthetic characteristic in lake waters and frequently determines the suitability of a waterbody for such recreational pursuits as game fishing and swimming. Discoloration and turbidity may be caused by growths of planktonic algae or by wastes. Clean freshwaters are likely to have transparency values (as measured by Secchi disk) greater than 3m except where influenced by humic material .

Chlorophyll

Chlorophyll is the green pigment of plants, containing magnesium, and concerned in the absorption of energy from sunlight in photosynthesis.

Chlorophyll is perhaps the single most important parameter in the assessment of the water quality of lakes, particularly in regard to their trophic status (i.e. to what degree they are enriched by the presence of nutrients such as phosphorus and to a lesser extent nitrogen in the form of nitrate). Excessive nutrient presence in lakes promotes the growth of algae which in overabundance cause serious environmental problems.

In over-enriched lakes (eutrophic) lakes "algal bloom" can occur. These are significant accumulations of cyanobacteria (formerly classified as blue-green algae), dense masses of algae which can be swept by winds along the lake shore (where they can decay, causing further problems), and which can seriously disrupt the dissolved oxygen regime.

Cyanobacterial and algal material can release trace organic components which can impair the amenity value of a lake and render it unfit for drinking in the case of it being a source of water supply. Algae can give rise to taste and odour problems.

There are no mandatory standards for chlorophyll concentrations in water and there are no references to the parameter in the various EU Directives relating to water quality. The EPA has adopted a trophic classification proposed in 1982 by the Organisation for Economic Cooperation and Development (O.E.C.D. 1982) and forms the basis for reporting lake water quality. The scheme is shown in Table B-5 : -

Quality Classes	Class A		Class B	Class C	Class A	
Quality Ratings	Q5	Q4	Q3-4	Q3	Q2	Q1
Pollution Status	Pristine, Unpolluted	Unpolluted	Slight Pollution	Moderate Pollution	Heavy Pollution	Gross Pollution
Organic Waste Load	None	None	Light	Considerable	Heavy	Excessive
Maximum B.O.D.	Low (< 3 mg/l)	Low (< 3 mg/l)	Occasionally elevated	High at times	Usually high	Usually very high
Dissolved Oxygen	Close to 100% at all times	80%-120%	Fluctuates from <80% to >120%	Very unstable Potential fish-kills	Low, sometimes zero	Very low, often zero
Annual Median ortho-phosphate	0.015 mg P/l	0.030 mg P/l	0.045 mg P/l	0.070 mg P/l	> 0.1 mg P/l	> 0.1 mg P/l
Siltation	None	May be light	May be light	May be considerable	Usually heavy	Usually very heavy and anaerobic
'Sewage Fungus'	Never	Never	Never	May be some	Usually abundant	May be abundant
Filamentous Algae	Limited development	Considerable growths. Diverse communities	Cladophora may be abundant	Cladophora may be excessive	May be abundant	Usually none
Macrophytes	Diverse communities. Limited growths	Diverse communities. Considerable growths	Reduced diversity. Luxuriant growths	Limited diversity. Excessive growths	Tolerant species only. May be abundant	Usually none or tolerant species only
Macroinvertebrates (from shallow riffles)	Sensitive forms usually numerous. Diverse communities. Normal density	Sensitive forms scarce or common. High diversity. Increased density	Sensitive forms scarce. Diversity may be high. Density High	Sensitive forms absent. Tolerant forms common. Low diversity	Tolerant forms only. Very low diversity	Most tolerant forms. Minimal diversity
Water Quality	Highest quality	Fair quality	Variable quality	Doubtful quality	Poor quality	Bad quality
Abstraction Potential	Suitable for all	Suitable for all	Potential problems	Advanced treatment	Low grade abstractions	Extremely limited
Fishery Potential	Game fisheries	Good game fisheries	Game fish at risk	Coarse fisheries	Fish usually absent	Fish absent
Amenity value	Very high	High	Considerable	Reduced	Low	Zero
Condition	Satisfactory	Satisfactory	Transitional	Unsatisfactory	Unsatisfactory	Unsatisfactory

Table B-6: *General Characteristics of Biological Quality Classes*

Lake Category	Total Phosphorous mg/m³	Chlorophyll mg/m³		Transparency m	
	mean	*mean*	*max.*	*mean*	*min.*
Ultra-Oligotrophic	<4	<1.0	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8.0	>6	>3
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hypertrophic	>100	>25	>75	<1.5	<0.7

Table B-5: *Trophic Classification Scheme for Lake Waters proposed by O.E.C.D.*

The level of lake monitoring carried out in Ireland does not permit the calculation of annual average values as specified in the OECD scheme. Instead a modified version of the OECD scheme is used in which the assessments are based solely on the annual maximum chlorophyll *a* concentration.

Chlorophyll measurements are normally performed in the summer and autumn months when the greatest planktonic algal growth is likely to occur.

In unenriched waters the annual mean and maximum chlorophyll levels are likely to be less than 8 and 25µg/l respectively (Bowman, 1996).

Phosphorus

Another important parameter in regard to lake water quality is phosphorus measured by the EPA as total phosphorus. See description under river water quality parameters.

B3.3 RIVER WATER QUALITY ASSESSMENT SYSTEMS

Republic of Ireland

Water quality assessment of surface waters in the Republic of Ireland is based on data collected from physico-chemical and biological surveys. The two methods complement each other and provide a more detailed and balanced picture of water quality than either one alone (McCumiskey, 1991). Sampling involves both river water samples and samples of the benthic substrate (sediment) in contact with the water. The river water sampling is carried on throughout the year whereas the biological surveys are normally carried out between June and October.

River water samples are generally analysed for conductivity, pH, colour, alkalinity, hardness, dissolved oxygen, biochemical oxygen demand (BOD), ammonia, chloride, ortho-phosphate, oxidised nitrogen and temperature.

The biological monitoring of rivers is based on the relationship between water quality and the relative abundance and composition of the macro-invertebrate communities in the sediment of rivers and streams. The macro-invertebrates include the aquatic stages of insects, shrimps, snails and bivalves, worms and leeches. The greater the diversity, the better the water quality (Table B-6).

The biological information is condensed to a 5-point numerical scale (Biotic Index or Q values), an arbitrary system in which community composition and water quality are related (Table B-7). The five grades used in the general assessment of river water quality have been grouped into four classes based on the water's suitability for beneficial uses (water abstraction, fishery potential, amenity value, etc.).

Biotic Index (Q value)	Quality Status	Quality Class	Condition
Q5, Q4-5, Q4	Unpolluted	Class A	Satisfactory
Q3-4	Slightly Polluted / Eutrophic	Class B	Transitional
Q3, Q2-3	Moderately Polluted	Class C	Unsatisfactory
Q2, Q1-2, Q1	Seriously Polluted	Class D	Unsatisfactory

Table B-7: *Biological River Water Quality Classification System*

Northern Ireland

The General Quality Assessment (GQA) system is used in the classification of river waters in Northern Ireland. General Quality Assessment examines a range of chemical and biological determinands which, taken together, describe the overall quality of the river environment.

Under the chemical GQA system river quality is separated into six discrete bands, from *Very Good* through *Fair* to *Bad*, using nationally accepted criteria. GQA uses three determinands to classify river reaches. These are Ammonia, Biochemical Oxygen Demand and Dissolved Oxygen.

GQA Class	Dissolved Oxygen (% saturation) 10-percentile	BOD (mg/l) 90-percentile	Ammonia (mg N/l) 90-percentile
A (Very Good)	> 80	< 2.5	< 0.25
B (Good)	> 70	< 4	< 0.6
C (Fairly Good)	> 60	< 6	< 1.3
D (Fair)	> 50	< 8	< 2.5
E (Poor)	> 20	< 15	< 9.0
F (Bad)	< 20	> 15	> 9.0

Table B-8: *Standards for Chemical GQA*

The biological GQA was developed more recently and is based on an assessment of the representativeness of the benthic invertebrate community of river reaches. Like the chemical GQA the biological GQA separates water quality into six bands from *Very Good* through *Fair* to *Bad*.

It should be pointed out that the chemical and the biological bandings are not directly comparable. Chemical water quality is assessed by analysis of the water itself while biological quality is inferred from the fauna found in the watercourse.

Macroinvertebrate data are summarised in Northern Ireland and Britain using the Biological Monitoring Working Party (BMWP) biotic score system. Under this method of data collation invertebrate groups or taxa are separated on the basis of their relative sensitivity to pollution with the more pollution sensitive taxa being allocated higher scores and the more pollution tolerant taxa being allocated lower scores.

Two other measures that describe biological quality are the number of BWMP scoring taxa present and the average pollution sensitivity of the macroinvertebrate community as described by the Average Score per Taxon (ASPT), which is derived from the community biotic score divided by the number of taxa represented.

The computer model RIVPACS (River Invertebrate Prediction and Classification System) developed in the UK was slightly modified to suit the organisms prevalent in the surface waters in Northern Ireland.

Comparison of the predicted macroinvertebrate communities with those observed during the biological sampling and analytical programme allows the calculation of ecological quality indices (EQIs). The most relevant EQIs in describing biological quality are those based on the number of macroinvertebrate taxa and on ASPT. These are derived from the equations:

EQI_{TAXA} = BMWP Observed Number of Taxa / BMWP Predicted Number of Taxa from RIVPACS

and

EQI_{ASPT} = BMWP Observed ASPT / BMWP Predicted ASPT from RIVPACS.

An EQI value of approximately one indicates that the observed macroinvertebrate fauna is what would be expected in an unstressed river reach, whereas lower EQI values reflect communities that are stressed to a lesser or greater degree. The agreed EQI bandings for the range of biological qualities are shown in Table B-9. Like the chemical GQA the biological GQA separates water quality into six bands from *Very Good* through *Fair* to *Bad*.

GQA Biological Class	EQI for ASPT	EQI for TAXA
A (Very Good)	> = 1.00	> = 0.85
B (Good)	0.90 - 0.99	0.70 - 0.84
C (Fairly Good)	0.77 - 0.89	0.55 - 0.69
D (Fair)	0.65 - 0.76	0.45 - 0.54
E (Poor)	0.50 - 0.64	0.30 - 0.44
F (Bad)	< 0.50	< 0.30

Table B-9: *Standards for Biological GQA*

B3.4 REFERENCES

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APPENDIX B4: FORMULAE TO ASSESS PROBABILITY OF POLLUTION INCIDENTS

B4.1 ACCIDENTAL HAZARDOUS SPILLAGE

The likelihood of a serious accident occurring, which might result in a hazardous spill, cannot be predicted with certainty. Nevertheless, it is estimated that increasing traffic densities and higher proportions of heavy goods vehicles (HGVs) are likely to lead to an increased risk of accidents that could give rise to hazardous spills. Furthermore, proximity to junctions and roundabouts also increases the risk of accidents. In the event of an accident resulting in a spill on the carriageway, the time required for the emergency services to arrive at the scene is also a factor in the estimation of the risk. HA216/06 of UK DMRB (Vol 11, Section 3, Part 10) 'Road Drainage and the Water Environment' provides a formula based on these factors to calculate the risk of serious accidental spillage leading to pollution. The formula is as follows:

$$P_{acc} = RL \times SS\ (AADT \times 365 / 10^{-9}) \times (\%HGV / 100)$$

where

P_{acc} = probability of a serious accidental spillage in one year over a given road length

RL = road length in kilometres

SS = serious spillage rates as reported by the UK DMRB (Table D1, Annex 1, Method D)

AADT = annual average daily traffic (in design year for new road)

%HGV = percentage of Heavy Goods Vehicles

The probability that a spillage will cause a pollution incident is calculated thus:

$$P_{pol/year} = P_{acc} \times P_{pol}$$

where

P_{pol} is the risk reduction factor, dependent upon emergency response times, which determines whether a serious spillage is likely to cause a serious pollution incident. Appropriate factors are suggested by the UK DMRB (Table D2, Annex 1, Method D)

Using the above approach, the probability of an accidental spillage, the risk reduction factor and probability of accidental spillage with resultant risk of serious pollution are calculated for each outfall along the proposed road and tabulated as indicated in Table B-10.

Outfall No.	Probability Accidental Spillage (% / Year)	Pollution Risk Reduction Factor	Annual Probability of Spillage with Resulting Serious Pollution (% / Year)
1			
2			
3			

Table B-10: *Accidental spillage - risk table*

The UK DMRB suggests that where the probability of a serious pollution incident is greater than 1%/year, spill-containment measures should be considered. It also suggests that, in particularly sensitive waters, areas at lower risk of serious pollution may also warrant special measures.

APPENDIX C : HYDROGEOLOGY, THE IRISH HYDROGEOLOGICAL ENVIRONMENT

Hydrogeological investigations and groundwater monitoring did not begin in Ireland until the late 1960s and early 1970s. The pace of investigation has increased significantly since the late 1980s. The management of groundwater quality in Ireland has recently been upgraded with the transposing of the EU Water Framework Directive into Irish law via the *European Communities (Water Policy) Regulations* (S.I. No. 722 of 2003). The Directive requires that waters are managed as individual river catchments.

C1 AQUIFER TYPE AND CLASSIFICATION

Aquifers consist of clean, coarse geological materials where permeability has developed in response to a variety of geological processes. There are a variety of aquifer types in Ireland. Limestone, dolomite, sandstone and volcanic strata are the main bedrock aquifers and poorly sorted sands and gravels are the dominant type of unconsolidated aquifers. Short descriptions of the principal aquifer types in Ireland are provided below.

Sandstones

Sandstones are sedimentary rocks in which the individual particles or grains range in size from 0.063mm (1/16mm) to 2mm. They may be either accumulated by wind action or deposited by water action and in the case of the latter they may form in marine, brackish or freshwater environments. In the Irish context, these are competent rocks that are often well-fractured or jointed as a consequence of geological stresses and movement. The Kiltorcan Sandstone Formation which occurs across southern Ireland provides substantial yields where well fractured and, as such, is considered an important aquifer.

Limestones

Limestones comprise the most extensive bedrock aquifers in Ireland. Those that are coarse grained, massive, well-fractured and interbedded with shales tend to have the greatest throughput, with well developed karst drainage to transmit large quantities of water underground. Of particular note are the regionally important karst limestones of western Ireland, which extend from Mayo to Clare. Many counties have areas underlain by regionally important karst and/or fractured aquifers.

Dolomites

Dolomites in Ireland are most extensive in the south-east of the country and are arguably the most productive aquifer in terms of conventional groundwater development. The alteration of limestones to dolomite by low-grade alteration can substantially increased bedrock porosity or permeability. The centres of this low grade alteration may occasionally be associated with mineralization of the bedrock, for example at both Galmoy and Lisheen mines.

Volcanics

Ordovician volcanics are an important aquifer in the south-east of Ireland, particularly in counties Waterford and Wexford, where rhyolites form an important bedrock aquifer.

Sands and Gravels

The sand and gravel deposits are Quaternary age deposits and are primarily of fluvio-glacial origin. Where these deposits are sufficiently thick and saturated, extensive and clean, they are considered to be important aquifers. They occur in different forms, e.g. as outwash plain (The Curragh in Kildare), delta (Blessington in Wicklow) or eskers (Rosemount and Ballymore in Westmeath). In Ireland, because of the part-glacial origin of the bulk of these deposits, they are very coarse and poorly sorted (well-graded) with a large throughput.

Where these deposits are less extensive, they often are an important part of the hydraulic regime of underlying bedrock aquifers, allowing a high percentage of effective rainfall to become recharge or providing additional storage.

The most productive aquifers are known and are quite well distributed throughout the island. They are generally not very extensive in area, aside from some of the karst limestone aquifers in the west of Ireland. In many instances, there is a tendency to overestimate the amount and extent of aquifers.

The major (Regionally Important) aquifers of Ireland are shown on Figure C-1 overleaf:-

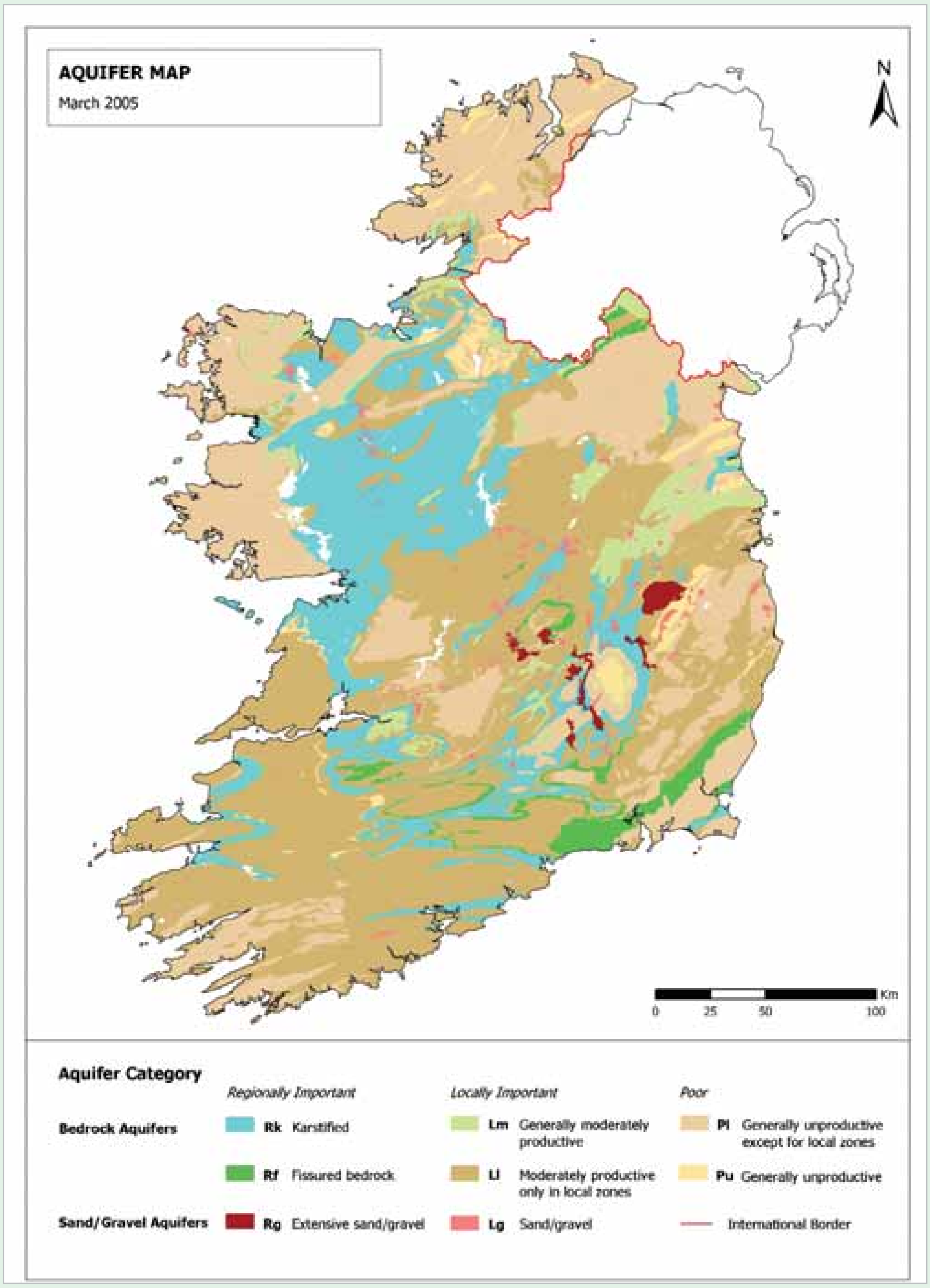

Figure C-1: *Aquifers of Ireland. National Aquifer Map - published by GSI.*

Aquitards

Most of the remaining geological strata are aquitards, i.e., poor aquifers or unproductive rocks that have little throughput and which are generally only capable of giving low yields to wells. These strata include the fine-grained sedimentary rocks (siltstones, mudstones and argillaceous limestones), intrusive igneous rocks and metamorphic rocks and are characterised by little throughput, few springs, small seeps and much rejected recharge.

The fine grained Quaternary deposits (tills, silts and clays) have little groundwater throughput as the saturated thickness is often thin and the permeability low. Nevertheless, these strata play an important role in the hydrogeology of underlying aquifers. Although they can restrict the amount of recharge getting to the aquifers, by diverting it to surface waters, they can, where sufficiently thick, isolate the aquifer from activities at the ground surface and provide protection.

Blanket bogs, raised bogs and fens are all characteristically developed over low permeability subsoils. Raised bogs and blanket bogs are characteristically hydraulically isolated from groundwater and fed by rainfall. However, fens are fed by surface water or groundwater and support ecology which is often reliant on groundwater / surface water interactions and the physiochemical properties of the water feed.

The physical properties of peat are unlike those of any other geological material. It has a very low dry matter content and flow is non-uniform (Darcian). Peat has a very high absorption capacity. The storage available in peat bogs reduces and delays winter floods and contributes groundwater to baseflow in summer and autumn.

Classification

Geological strata are classified for hydrogeological purposes as one of three principal types:-

- Major (Regionally Important) Aquifers
- Minor (Locally Important) Aquifers
- Unproductive Rocks (Poor Aquifers) or Aquitards.

The Geological Survey of Ireland further sub-divides the aquifer categories on the basis of aquifer type (ie. bedrock / sand and gravel) and a qualitative assessment of the dominant flow type. As of October 2006, GSI identifies 10 aquifer categories. These are as follows:

Regionally Important (R) Aquifers

- Karstified bedrock dominated by diffuse flow (Rkd)
- Karstified bedrock dominated by conduit flow (Rkc)
- Fissured bedrock (Rf)
- Extensive sand & gravel (Rg)

Locally Important (L) Aquifers

- Sand and gravel (Lg)
- Bedrock which is Generally Moderately Productive (Lm)

- Bedrock which is Moderately Productive only in Local Zones (Ll)
- Locally important karstified bedrock (Lk)

Poor (P) Aquifers

- Bedrock which is Generally Unproductive except for Local Zones (Pl)
- Bedrock which is Generally Unproductive (Pu)

In reality there is little difference between the bedrock classifications of the Locally Important and Poor Aquifer categories.

C2 AQUIFER CHARACTERISTICS

Groundwater is defined as sub-surface water that occurs within the saturated zone of an aquifer. In terms of the hydrological cycle, groundwater can act as a long-term storage for water, with residence times from days to millennia. Groundwater is recharged from the surface (see Section B1.1, Appendix B1) and returns to the surface via seeps and springs, at fens, or as part of groundwater-surface water interaction within drainage basins.

The balance between seasonal recharge, interaction with surface water and groundwater discharge results in a fluctuation in the groundwater levels across the year. The water table tends to be at its lowest during the mid-autumn and at it's highest in late winter, although this will vary depending on the infiltration rate and thickness of the unsaturated zone. The extent of the water table fluctuation is largely dependant to the amount of recharge applied and the properties of the aquifer. For example, in a high storage aquifer such as a sand and gravel, the water table may rise and fall over a range of 2m; however, in a low storage fractured limestone aquifer, the fluctuation for the same quantity of recharge may be 10m.

An aquifer is defined as a geological formation that is capable of yielding significant quantities of water. However, 'significant' can range from a supply of 50,000m^3/day for a city or large industry, down to 500m^3/day for a domestic supply or small farm. On this basis most rock types are aquifers; however, their sustainable supply will encompass a broad range. The terms aquitard or aquiclude are often used to refer to low yielding aquifers, that confine higher yielding aquifers. On this basis unconsolidated subsoil, crystalline rock and consolidated rock are all aquifers; however, they differ in terms of how water is stored and transmitted. These characteristics of an aquifer are measured by their hydraulic properties, which include porosity, permeability and specific yield.

Porosity (%) is the measure of void space in relation to the bulk volume of the subsoil or rock (refer to Table C-1 below). Void space that formed at the same time as the subsoil/rock is referred to as primary porosity. However, if the void space occurs due to later processes, such as faulting or chemical alteration/dissolution, then it is referred to as secondary porosity.

Subsoil	Porosity (%)	Bedrock	Porosity (%)
Topsoil	50-55	Limestone	0.5-5
Clay	30-60	Sandstone	0.5-5
Silt	30-50	Granite	0.1-5
Well sorted sand or gravel	25-40		
Sand and gravel mixes	10-30		
Till (boulder clay)	10-30		
Undrained peat	>85		

Table C-1: *Typical Porosity Ranges (Fitzsimons, 2003)*

Permeability (m/s) (or *hydraulic conductivity*), is the measure of the ability of subsoil/rock to transmit water. In subsoils, intergranular permeability dominates, whilst in rock, fissure permeability (via fractures and bedding discontinuities) dominates.

Specific yield (%) indicates the amount of water released from an aquifer due to drainage. By definition, it is always less than porosity due to retention of some groundwater by the subsoil/rock.

In general those aquifers with a high primary porosity, such as unconsolidated sands and gravel deposits have a high permeability and specific yield, and those aquifers with a low porosity, such as consolidated shales or most crystalline rocks, have a low permeability and specific yield. Some of Ireland's most productive aquifers are unconsolidated sands and gravels, the largest of which is the Curragh aquifer of Kildare (200km^2).

Ireland is unusual within the European context as it lacks the large-scale highly productive bedrock aquifers that have a high primary porosity and intergranular permeability. Instead groundwater supply in Ireland relies on bedrock aquifers that have a low primary porosity but a high secondary porosity and fissure permeability. Secondary enhancement of aquifer properties affects all consolidated rock; however, none more so than karst limestones, where the secondary porosity can be enhanced into conduit systems and caves by chemical dissolution. The porosity of limestones may also be enhanced by dolomitisation, which is common along faults and fractures.

C3 HYDROCHEMISTRY / WATER QUALITY

The hydrochemical constituents of any groundwater are a representation of the processes occurring with the aquifer. These processes are natural but can be influenced by anthropogenic (human) activities. As the majority of Irish aquifers are limestones and covered by subsoils derived from limestone, the groundwater hydrochemistry is typically elevated with respects to calcium, magnesium and bicarbonate ions. Limestone groundwaters may also have elevated iron, manganese, sodium and fluoride. Where sodium and fluoride is abundant, the recharge and throughput of the aquifer is likely to be low. In areas where sandstone or volcanic rocks are present, the water tends to be less hard than in limestone areas.

Groundwater quality is normally a function of anthropogenic (human) influences; however, groundwater quality can also be poor because of natural features such as elevated iron, manganese or fluoride levels. The quality of many groundwaters has been impacted by elevated nitrate concentrations, which has originated through poor agricultural and wastewater management practices. The concentration of contaminants in groundwater is influenced largely by proximity to source and the vulnerability of the aquifer.

Many houses in rural areas are often not connected to a mains sewage treatment plant. In these areas treatment is provided mainly by septic tanks and soakpits or percolation areas, which can have an adverse impact on water quality. Many newer houses however are connected to package wastewater treatment systems and percolation areas, which have a reduced impact on groundwater, *provided they are regularly maintained*.

C4 VULNERABILITY

Vulnerability is the term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities. The vulnerability of groundwater depends on the time of travel of infiltrating water (and contaminants), quantity of contaminants and the attenuation capacity of the geological materials through which the water and contaminants infiltrate.

The travel time, attenuation capacity and quantity of the contaminants are a function of the following natural geological and hydrogeological characteristics;

- the type and thickness of subsoils that overlie the groundwater body
- type of contaminant recharge (point or diffuse)
- the thickness of the unsaturated zone through which the contaminant moves, and
- the hydraulic conditions (ie. confined or unconfined)

In general, the greater the thickness of low to medium permeability subsoil deposits (clay/silt), the greater protection from potential contaminants is afforded to the underlying groundwater resource. The GSI vulnerability mapping guidelines are shown in Table C-2. below.

Vulnerability Rating *	Hydrogeological Conditions				
	Subsoil Permeability (Type) and Thickness			Unsaturated Zone	Karst Features
	High Permeability (eg. sand and gravel)	Moderate Permeability (eg. sandy subsoil)	Low Permeability (eg. clayey subsoil, clay, peat)	(Sand / Gravel Aquifers only)	(<30 m radius)
Extreme (E)	0 - 3.0 m	0 - 3.0 m	0 - 3.0 m	0 - 3.0m	–
High (H)	> 3.0 m	3.0 - 10.0 m	3.0 - 5.0 m	> 3.0 m	N/A
Moderate (M)	N/A	> 10 m	5.0 - 10.0 m	N/A	N/A
Low (L)	N/A	N/A	> 10 m	N/A	N/A

Table C-2: *Vulnerability Assessment Criteria (from DoELG, EPA, GSI - 1999)*

** This system assumes unconfined hydraulic conditions which are not always present in nature.*

The aquifer vulnerability map of Ireland is reproduced as Figure C-2 below

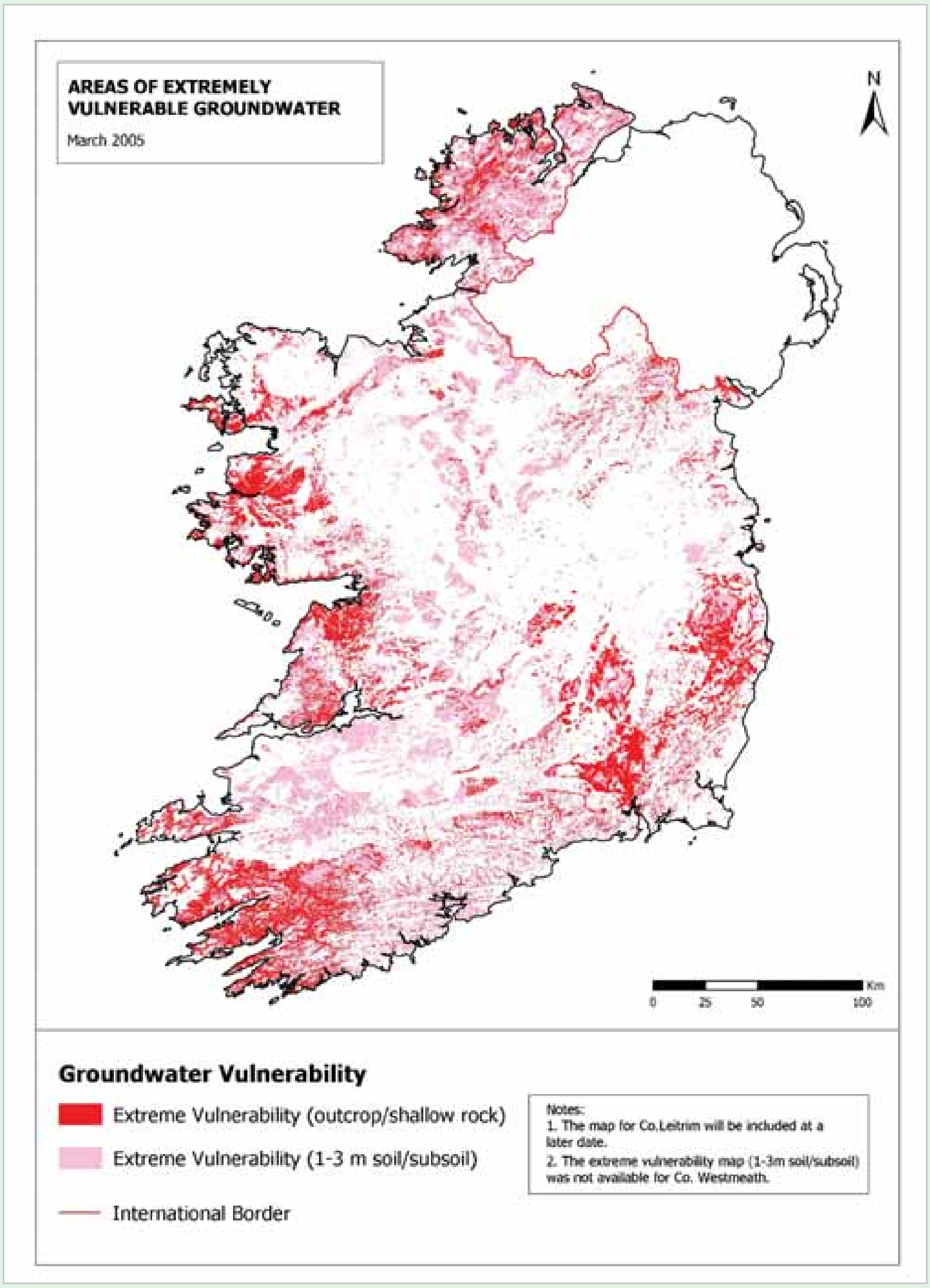

Figure C-2: *Aquifer Vulnerability Map of Ireland. Extremely Vulnerable Groundwater - published by GSI*

C5 KARST HYDROGEOLOGY

Karst environments are valued for several reasons. They contribute large volumes of water to river baseflow, they are often important sources of water supply, they support distinctive groundwater dependent habitats and they contain cave systems which provide a distinctive habitat for flora and fauna, often contain archaeological remains and are used for leisure pursuits (caving) or developed as tourist attractions (showcaves). Turloughs have a water chemistry which supports many unusual freshwater flora and fauna. (Refer to NRA *Guidelines for Assessment of Ecological Impacts of National Road Schemes*). The construction of national road schemes in karst environments can present significant hydrogeological challenges, particularly with respect to protection of groundwater quality and sensitive groundwater-fed ecosystems.

Historically, karst hydrogeology has been associated with the limestone uplands of Ireland, specifically those of Counties Clare, Leitrim, Sligo and north Mayo, where large river cave systems such as Pollnagollum Cave (Burren, Co. Clare) and Aille River Cave (Co. Mayo) are found. Due to the low population destiny in upland areas, these types of grand-scale karst rarely tend to be affected by socio-economic development.

By comparison however, lowland karst tends to be of a less grand scale and due to its abundance it frequently occurs within populated areas (Drew, 2007) and is impacted by socio-economic development (water supply or infrastructure projects). Lowland karst is frequently encountered in the west of Ireland from Sligo and Roscommon through to south Mayo and in Counties Galway, Clare and Limerick. In these areas the limestone bedrock it is often exposed at the surface or has only thin subsoil cover. In the east, the lowland karst is less extensive and generally has thicker subsoil cover. Counties Monaghan, Louth, Offaly and Laois however all contain karst landforms, while County Kilkenny has numerous karst landforms including several large springs that contribute significant baseflow to the River Nore. Lowland karst includes landforms such as dolines (closed depressions), stream sinks, turloughs and occasionally caves, all of which are generally shallow and within the upper 30m of bedrock. All of these landforms tend to act as point inputs of surface water to groundwater.

Karst in the southern counties of Ireland is known as valley karst and differs in a number of ways from the lowland karst further north. Limestone in the southern counties is intensely folded as a result of a mountain-building period at the end of Carboniferous era. This folding created an extensive system of faults and fractures in the rocks which were subsequently enlarged by dissolution, forming karst systems. Valley karst occurs in Counties Tipperary, Cork and Waterford, as well as in the valley around Castleisland and Tralee in Kerry.

All karst landforms have evolved by the enlargement (largely by solution) of preferential groundwater flow paths along geological discontinuities (horizons / planes). The timescale for their development varies quite widely. Shallow landforms are often relatively recent in their development (<10,000 years). However, development of many conduit systems starts in deep, hydrogeologically confined settings (Lowe, 1992, 2005; Klimchouk, 2005) and their formation can be particularly extended and complex.

A diagram illustrating drainage in limestone areas is presented in Figure C-3 below. It shows surface inputs from dolines and stream sinks draining towards conduits developed at a shallow depth in the limestone. These conduits originally have a water surface (vadose) but are often water-filled (phreatic), particularly at depth. Flow velocities within such conduits can often exceed 100m/h, which has implications in terms of aquifer vulnerability and groundwater protection. The high vulnerability of karst aquifers has resulted in exclusion zones being applied to the perimeter of surface landforms for activities such as landspreading.

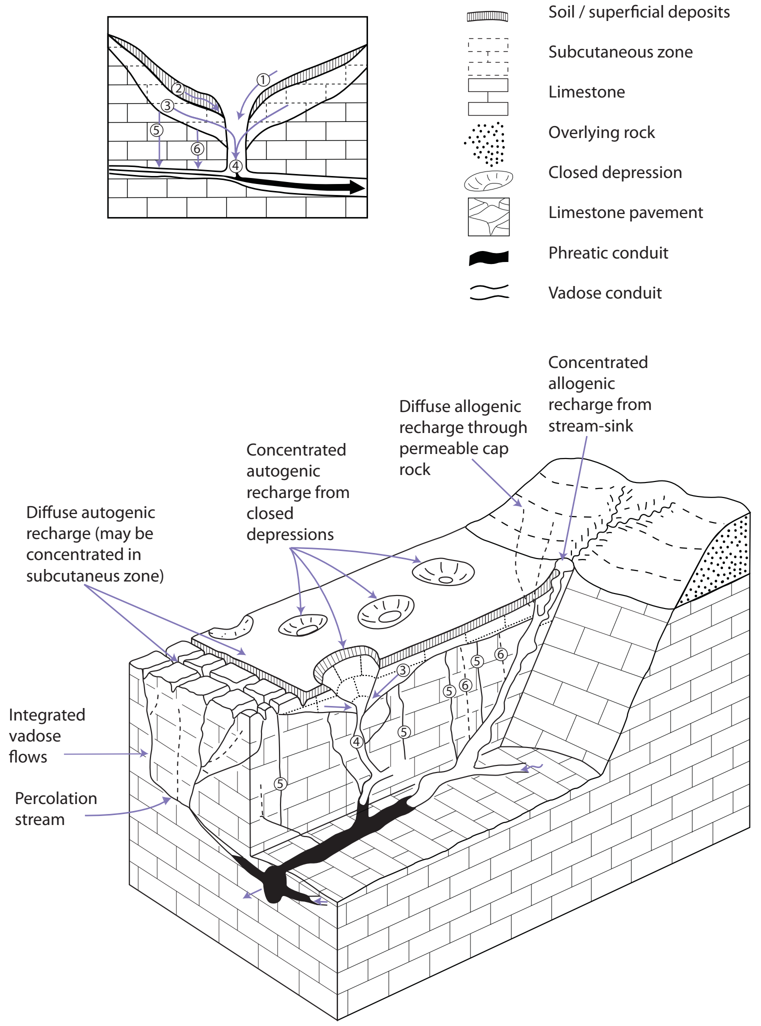

Figure C-3: *Conceptual Model for Drainage of Limestone Areas. From GSI publication - The Karst of Ireland - Daly et al. (2000), in turn taken from Gunn (1986)*

(1) Overland flow
(2) throughflow
(3) subcutaneous flow
(4) shaft flow
(5) vadose flow;
(6) vadose seepage. (Gunn, 1986)

One karst landform that is almost unique to Ireland is the turlough (Gunn, 2006). An estimated several hundred turloughs are known in the Republic of Ireland; however, only three occur in Northern Ireland and only one in Wales, which is the only known turlough outside the island of Ireland (Gunn *et al*., 2006). A turlough (Gaelic for *pasture land lake*) is a seasonal lake, which is a representation of the groundwater level within the aquifer. Although some turloughs have a surface stream inflow, by definition a turlough is a closed depression that has a spring(s) and sink(s), which is flooded during the winter months but dry during the summer. A schematic of a turlough is presented in Figure C-4 below.

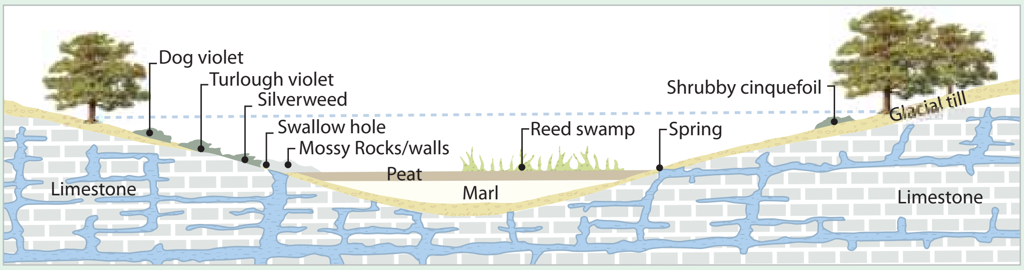

Figure C-4: *Cross-section Through a Turlough (Daly et al., 2000 - adapted from Coxon, 1986)*

C6 HYDROGEOLOGICAL RESOURCES

Groundwater is an integral part of the hydrological cycle. In rivers with a significant area of major aquifers, it is an important component of river and stream flow. The mean groundwater component of the River Nore, at the Brownsbarn Gauging station near Inistioge, has been estimated to be about 50% of total runoff (Daly, 1994). During dry periods in late spring, the summer and early autumn, groundwater baseflow can constitute almost the entire flow in some rivers.

Groundwater flow supports many different types of wetland habitat ecosystems throughout the country which are noted for their fauna and/or flora. Many of these sites are protected by European and Irish environmental legislation. Deposits from calcium rich groundwaters formed the low permeability marls on which fen peat wetlands developed and are sustained eg. Pollardstown Fen in County Kildare and Bellacorrick Iron Flush in County Mayo. Many important turlough habitats which principally occur in the west of Ireland are essentially controlled by the inflow and outflow of groundwater. Examples include Rahasane turlough, near Craughwell, County Galway, Ballynacarrick turlough near Ballyshannon, County Donegal and the Lackens and Galmoy, near Johnstown in County Kilkenny

There are small springs in some areas that are referred to as '*holy wells*' which often have a cultural significance. They inevitably have a saint's name (Saint Brigid) and are often marked on the OS 1:50,000 maps. If the emergent groundwater has circulated to a significant depth then they may have elevated temperatures and be regarded as thermal springs, such as Kilbrook near Enfield, County Meath.

As mentioned previously, groundwater developed via springs, dug wells and boreholes is a major, and increasingly important, source of water supply, particularly outside the principal urban centres in the State. It is a reliable and relatively inexpensive source of water. Groundwater from springs or medium to high yielding boreholes (>150m^3/d or 1,400gph) or wellfields (generally >1,000m^3/d or 9,170gph) is the main source of water supply for domestic use, commercial enterprises and industrial use in many parts of the country. Local Authorities use large springs to supply towns such as Abbeyleix in County Laois and Castlerea in County Roscommon and regional water supply schemes in the Dunmore-Glennamaddy area of County Galway and Paulstown in County Kilkenny. They use boreholes or wellfields to supply parts of north-east Cork, Portlaoise and parts of Monaghan Town.

Groundwater is used by many filling stations in south Dublin to supply their car-wash facilities and has long been the source of cooling water for the milk processing industry.

Many villages and rural areas in Ireland are provided with groundwater sourced supplies that are administered locally by Group Water Supply Schemes. The scheme at Ballacolla in County Laois uses a number of spring sources, whereas the scheme at Tydavnet in County Monaghan uses a number of high yielding wells.

Beyond the Local Authority or Group Water Scheme water mains, water supplies for individual houses and farms are provided almost exclusively by low yielding boreholes, dug wells or springs/seeps. The presence of such wells is often indicated by small pumphouses of varied construction standing alone from other development in gardens or fields. It is estimated that there are of the order of 200,000 such wells in Ireland. The numbers in individual areas can vary from less than 1 well/km^2 in isolated and unpopulated areas to over 5 wells/km^2 around some of the urban centres in the midlands. The small springs or seeps that are used as a water supply have usually been deepened into shallow 1-2m dug wells.

Most of dug wells used for domestic or farm water supplies range from about 3m to 10m in depth, although there are a number that are known to extend to over 30m. Such wells are typically about 2m in diameter at the top reducing to 1m at the bottom. These wells are lined with stone or concrete to bedrock and are open if they extend into bedrock. Up until the 1960s, such wells were excavated by hand. These wells are generally not that productive, however they do hold significant quantities of water in storage (up to 5m^3)

Boreholes drilled for domestic and farm supply are typically 20m to 60m in depth, although they can be up to 90m deep. The majority of these wells are completed with 150mm steel casing to bedrock and are open in bedrock thereafter. These wells generally yield between 10m^3/d and 40m^3/d. In some rock strata, it is not uncommon to fail to obtain even the minimum requirement (10m^3/d) with boreholes in excess of 75m deep. The standard of well location, completion and protection is often very poor with the result that water quality in many low yielding domestic and farm wells is unsatisfactory.

Roadside wells (hand pumps), some dating from the 19th century, are still a feature in many parts of Ireland. The older ones are generally stone lined and can be quite deep. Installation records for these wells are often useful for identifying the depth of the water table in a locality. The roadside wells constructed in the 1940s and 1950s in a number of counties were drilled with cable tool rigs and are completed to a design similar to that of domestic or farm wells.

C7 SUMMARY

Major aquifers, high yielding springs and boreholes are well distributed throughout Ireland. Groundwater makes an important contribution to flow in streams and rivers, supports wetland ecosystems and is used throughout the country as a source of water supply. The principal characteristics of the groundwater regime in Ireland can be summarised as follows:

- major aquifers, extending over approximately a quarter of the island,
- rainfall is plentiful and well distributed throughout the year
- fissure flow predominates in the bedrock aquifers, storage is relatively low, but throughput can be quite rapid, particularly near the surface
- hydraulic conditions are variable and flow paths are mainly shallow and short
- water tables are generally within 10m of the surface although there notable exceptions in a few areas
- bedrock aquifers are often overlain by Quarternary (unconsolidated) deposits whose lithology, thickness and permeability are variable
- water quality is generally good, although rising nitrate levels in some areas are a problem.

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D GLOSSARY

GEOLOGICAL TERMS

Alluvium	Deposits from a river or stream.
Amphibolite	A coarse grained, dark coloured regional metamorphic rock. Formed from the metamorphism of igneous rocks.
Basalt	A dark, dense extrusive volcanic rock. Basalt is the most abundant volcanic rock in the Earth's crust.
Belt	A linear or arc region characterised by compressional tectonics.
Biomicrite	Limestone formed from very fine grained carbonate mud and fossil fragments
Calcareous	Composed of, or containing, calcium carbonate.
Calcareous Marl	A fine grained sediment intermediate between clay and limestones, and includes gradations between calcareous clays and muddy limestones. Often found in shallow lakes with much vegetation and also associated with evaporite deposits.
Cave	A naturally occurring cavity large enough for human access
Chalk	A very pure soft white limestone formed of calcite, and containing only small amounts of silt of mud.
Chert	A type of sedimentary rock consisting primarily of microscopic silica crystals.
Clastic	Applied to the texture of fragmented sedimentary rocks.
Coal	A member of a group of easily combustible, organic sedimentary rocks composed mostly of plant remains and containing a high proportion of carbon.
Conglomerates	A rock produced by consolidation of gravel; constituent rock and mineral fragments are usually varied in composition and size.
Corrie	A steep-walled semicircular basin in a mountain formed by ice accumulation.
Dips	The angle of inclination which the bedding plane of rocks makes with a real or imaginary horizontal plane.
Dissolution	A form of chemical weathering in which water molecules, sometimes in combination with acid or another compound in the environment dissolve parts of a mineral or rock.
Dolerite	A dark coloured fine- to medium-grained intrusive igneous rock composed of plagioclase feldspar and pyroxene.
Doline	A steep sided, enclosed depression in a limestone region. It is normally located at a site of increased joint density, which focuses drainage passing vertically through the rock.
Dolomite	A calcium-magnesium carbonate mineral ($(Ca,Mg)CO_3$), or a rock composed largely of the mineral dolomite.
Downthrow	The vertical distance rocks on one side of a fault have moved downwards relative to the rocks on other side
Drift Geology	Any sediment laid down by, or in association with, the activity of glacial ice.
Drumlin	A long, egg-shaped hill that develops when pressure from an overriding glacier reshapes a moraine. Drumlins range in height from 5 to 50 meters and in length from 400 to 2000 meters. They slope down in the direction of the ice flow.
Dyke	A tabular intrusive rock cross-cutting the host strata at a high angle.
Esker	A ridge of sediment that forms at the base of a stream flowing under a glacier, made up of sand and gravel deposited by meltwater.

Estuarine	Environment associated with semi-enclosed coastal body of water which has a free connection with the open sea and where fresh water, derived from land drainage, is mixed with sea water.
Evaporites	Minerals or rocks formed by the evaporation of saline water.
Fault	A fracture in rock along which there has been relative displacement of the two sides.
Fluvial	Pertaining to a river.
Foliated	Laminated, parallel orientation or segregation of different minerals.
Folds / Folded	A flexure or bend in rock strata or any planar feature produced when rocks were in a plastic condition.
Glacial till	Glacial sediment that is deposited directly from glacial ice and therefore not sorted. Also called till.
Glaciated Valley	A river valley that has been glaciated, usually to a typical U-shaped, cross-section.
Gneiss	A coarse-grained, foliated metamorphic rock marked by bands of light-coloured minerals such as quartz and feldspar that alternate with bands of dark-coloured minerals. This alternation develops through metamorphic differentiation.
Greensands	A glauconite-rich sandstone and calcareous sandstone
Greywacke	A grey sandstone consisting of poorly sorted grains of quartz, feldspar, and rock fragments in a clay matrix.
Gypsum	Hydrated Calcium Sulphate ($CaSO_4.H_2O$) forms as an evaporite around hot springs, and in clay beds.
Halite	Common rock salt, sodium chloride (NaCl). This is an evaporite mineral, formed by the precipitation, as the water in a salt lake, or lagoon dries out.
Igneous Rock	Rocks that have solidified from a molten state.
Inlier	Structure where older rocks are surrounded completely by younger rocks. It may result from faulting or folding followed by erosion.
Intrusive	A body of rock, usually igneous, that is emplaced within pre-existing rocks.
Joint	A fracture dividing a rock into two sections that have not visibly moved relative to each other. See also fault.
Kame	A low, long, steep-sided mound of glacial drift, commonly stratified sand and gravel, deposited as an alluvial fan or delta at the terminal margin of a melting glacier.
Karst	A topography characterized by caves, sinkholes, disappearing streams, and underground drainage. Karst forms when groundwater dissolves pockets of limestone, dolomite, or gypsum in bedrock.
Kettle Hole	A small, often round landform depression formed as a result of glacial movement. It is formed when a large piece of ice breaks away from the edge of a retreating glacier, and becomes partially buried under sediment deposited by the glacier. After it melts, this fragment leaves a small depression in the landscape.
Lacusterine	Pertaining to a lake.
Lignite	A soft, brownish coal that develops from peat through bacterial action, is rich in kerogen, and has a carbon content of 70%, which makes it a more efficient heating fuel than peat.
Limestone	A sedimentary rock composed primarily of calcium carbonate. Some 10% to 15% of all sedimentary rocks are limestones. Limestone is usually organic, but it may also be inorganic.
Lithification	The conversion of loose sediment (unlithified material) into solid sedimentary rock (lithified material).

Mafic	Igneous rock largely composed of iron and magnesium rich minerals
Marble	A coarse-grained, non-foliated metamorphic rock derived from limestone or dolomite.
Metabasite	A collective term, first used by Finnish geologists, for metamorphosed mafic rock that has lost all traces of its original texture and mineralogy owing to complete recrystallization.
Metamorphic	A rock that has undergone chemical or structural changes due to the influence of extreme temperature or pressure in the crust of the Earth.
Metasediments	Material derived from pre-existing rock which has undergone metamorphism.
Micrite	Limestone formed from very fine grained carbonate mud
Moraine	A single, large mass of glacial till that accumulates, typically at the edge or end of a glacier.
Mudstone	Argillaceous or clay-bearing sedimentary rock which is non-plastic and has a massive non-foliated appearance.
Non-scheduled Mineral	Any substance obtained on, in or under land which is not mentioned in Schedule to Minerals Development Act (1940)
Organic	Pertaining to, or derived from life.
Outlier	An area where younger rocks are surrounded completely by older rocks. It may be produced by erosion, faulting or folding or any combination of these.
Paragneiss	A gneiss formed by the metamorphism of a sedimentary rock
Periglacial	Any environment where the action of freezing and thawing is currently, or was during the Pleistocene, the dominant surface process.
Permeability	The ability of a rock, sediment, or soil to permit fluids to flow through it.
Pingo	A low hill or mound forced up by hydrostatic pressure in an area underlain by permafrost and consisting of an outer layer of soil covering a core of solid ice.
Porosity	The total of all void spaces present withina rock, but not all these spaces will be interconnected and thus able to contain and transmit fluids.
Psammite	Metamorphosed sandstone.
Quartz	A silicate mineral (SiO_2), one of the most widely distributed rock-forming minerals.
Quartzite	An extremely durable, non-foliated metamorphic rock derived from pure sandstone and consisting primarily of quartz.
Salt	Sodium Chloride; also called halite or rock salt.
Sandstone	A clastic rock composed of particles that range in diameter from 1/16 millimetre to 2 millimetres in diameter. Sandstones make up about 25% of all sedimentary rocks.
Schist	A strongly foliated metamorphic rock that develops from mudstone or shale and splits easily into flat, parallel slabs.
Scheduled Mineral	Any substance obtained on, in or under land which is mentioned in Schedule to Minerals Development Act (1940)
Sedimentary	A rock formed from the Lithification of sediment. Clastic sediments refer to the fragments of eroded material (sandstone, siltstone and shale). Chemical sediments include salt, gypsum etc. Limestones may be chemical sediments but are typically organically-derived being composed of the remains of animals with calcium carbonate bodyparts.
Shale	A rock formed from fine-grained clay-size sediment.
Shear	Low-angle plane of failure in faulted body of rock.
Siltstone	A typically layered and flaggy rock composed of two thirds silt-sized particles.

Slate	A fine-grained, foliated metamorphic rock that develops from shale and tends to break into thin, flat sheets.
Solifluction	Slow downhill movement of soil that has been saturated with water.
Structural Trend	The azimuth of a geological feature, commonly of a fold axis.
Tectonism	Deformation within the Earth's crust and its consequent structural effects.
Till	A glacial sediment composed of rounded rock fragments in a clay rich matrix.
Unconsolidated	Applied to particles that are loose and not cemented together.
Volcanic	An igneous rock formed from lava that has flowed out onto the Earth's surface, characterised by rapid solidification.

HYDROLOGICAL TERMS

95-Percentile Flow	The flow rate (expressed in m^3/s) at a given location on a river which over the long-term is equalled or exceeded 95% of the time
Acidification	The process of becoming an acid or becoming acidic. In the case of lake acidification, acidic waters either sourced from the ground or from rainfall can, over time, cause the water body to change from alkali to acid. While this process has been occurring naturally since the last ice age, it is also caused by pollution or contamination.
Actual Evapotranspiration (AE)	(see evapotranspiration below) Under certain circumstances, such as dry weather, then the quantity of water available to crops is reduced. During this time, the actual evapotranspiration is reduced below the potential evapotranspiration. Calculation of AE incorporates a stress factor that is based upon the soil moisture balance.
Base Flow	The groundwater contribution to a surface water course is referred to as base flow. It is the component of the surface water flow not derived directly from run-off. The base flow component of a stream or river volume depends on the hydraulic properties of the contributing aquifer.
Dry Weather Flow	The annual minimum daily mean flow rate (expressed in m^3/s) at a given location on a river with a probability of exceedance of 0.98 (i.e. with a return period of 50 years)
7-Day Sustained Low-Flow	The flow rate (expressed in m^3/s) that is not exceeded for 7 consecutive days in any year.
Return Period	The frequency with which a certain event would be expected to occur on average over a long period of record.
Catchment	That area determined by topographic features within which falling rain will contribute to run-off at a particular point under consideration.
Eutrophication	Eutrophication is the effect of an increase in compounds containing nitrogen or phosphorus in an ecosystem. The term is often used in reference to the resultant increase in the ecosystem's primary productivity (excessive plant growth and decay), and further effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations.
Evapotranspiration	Evaporation from a surface covered by vegetation (usually grass). It depends on both meteorological conditions and on the type of vegetation and is also influenced by the soil moisture status. The term evapotranspiration is used to indicate the combined amount of water evaporated from the soil surface and transpired from the soil moisture storage through vegetation.

Potential Evapotranspiration (PE)	the term used to describe the process under conditions of unrestricted availability of water at the vegetation surface. In drier conditions, actual evapotranspiration is usually less than PE. The term potential evapotranspiration (PE) is used when the water supply available to the plant is not limited. If the water supply in the soil is limited, the actual evapotranspiration (AE) will be less than the potential value.
Peak River Flow	The maximum flow attained for a particular river. Usually in m^3/s.
Potential Surface Runoff	The theoretical calculation of runoff using rainfall and potential evapotranspiration. The actual surface run-off is less than the potential due to rainfall being lost to ground as recharge.
Precipitation	Any form of water, such as rain, snow, sleet, or hail, that falls to the earth's surface
Mean Annual Maximum Flow	Maximum flow per annum for the full dataset presented as a mean value.
RAW	Readily Available Water. Used in soil moisture balance calculations to determine the quantity of actual evapotranspiration.
Specific Run-off	Runoff per unit area (m/yr)
TAW	Total Available Water. Used in soil moisture balance calculations to determine the quantity of actual evapotranspiration.

HYDROGEOLOGICAL TERMS

Aquifer	A permeable geological stratum or formation that can both store and transmit water in significant quantities.
Aquitard	A geological stratum of low permeability that can store groundwater, but is only capable of transmitting water slowly between aquifers.
Baseflow	That part of the flow in a stream which is not attributable to direct runoff from precipitation or snowmelt, usually sustained by groundwater discharge.
Confined Aquifer	An aquifer which is overlain by impermeable geological strata; confined groundwater is generally subject to pressure greater than atmosphere.
Conduit Flow	A characterisation of some types of Karst aquifers, in which flow is concentrated in conduits created by the dissolution of the limestone bedrock.
Darcian Flow	Flow that can be modelled by variations of Darcy's Law of flow through porous media. Generally uniform and laminar (no turbulence).
Diffuse Flow	A characterisation of some types of Karst aquifers, in which flow is distributed relatively evenly throughout the rock.
Effective Rainfall	The amount of rainfall that will be able to reach the underlying aquifer. It is determined as the actual rainfall, less evapotranspiration and soil moisture deficit.
Fissure	Natural crack in rock which allows rapid water movement.
Karst Feature	Landscape feature which results from karstification (solution of limestone) such as a turlough, swallow hole, cave, etc.
Perched Water Table	When impermeable strata or lenses are present in the subsurface, the volume immediately above the impermeable unit can become saturated as the water is unable to percolate further down into the aquifer. The convex surface that this creates is a perched water table.
Piezometric Surface	(Or potentiometric surface) The surface representative of the level to which water will rise in a well cased to the impermeable layer above a confined aquifer. In unconfined aquifers, this surface corresponds with the water table.

Point (Pollution)	SourceAny discernible, confined, or discrete conveyance from which pollutants are or may be discharged, including (but not limited to) pipes, ditches, channels, tunnels, conduits, wells, containers, slatted sheds and animal rearing sheds.
Phreatic cave	A cave that has developed below the water table, where all voids are completely water filled.
Recharge	The addition of water to the zone of saturation; also, the amount of water added.
Saturated Zone	The zone below the water table in which all pores and fissures are full of water.
Sinkhole	Also referred to as a doline. A natural depression in the land surface formed by solution or collapse of bedrock (most commonly limestone) or by the suffusion of unconsolidated soils / subsoils infilling a solution or collapse landform.
Spring	A flow of water that occurs where the water table intercepts the ground surface.
Storage	The volume of water held within a certain volume of saturated aquifer.
Turlough	Seasonal lake which occurs in winter and early spring when the groundwater table rises above the land surface
Unconfined Aquifer	An aquifer where a water table has developed, separating the unsaturated zone above from the saturated zone below.
Unsaturated Zone	The zone between the land surface and the water table, in which pores and fissures are only partially filled with water. Also known as the vadose zone.
Vadose cave	A cave that is located above the water table. Drainage is free-flowing under gravity, and cave passages therefore have air above any water surface.
Water Table	The surface at which pore water pressure in an aquifer is equal to atmospheric pressure, and which separates the saturated zone from the unsaturated zone.

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