1987

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH GROUP)

7TH ANNUAL SEMINAR

KILLESHIN HOTEL, PORTLAOISE

PROGRAMME

Tuesday 7th April

10.15 a.m.	Registration and Coffee		
10.45	Welcome and Introduction	Mr. P. Bennett	(President, IAH Irish Group)
11.00	Policy for Aquifer Protection	Dr. A. Skinner	(Severn-Trent Water Authority)
12.00	Aquifer Protection Policy in Ireland ....Case Study (1)	Mr. M. Hand	(P.H.McCarthy, Son & Ptrs)
12.30 p.m.	.......Case Study (2)	Mr. K. Cullen	(Consultant)
1.00	Lunch		
2.30	Aquifer Protection Policy - Discussion		
3.15	Septic Tanks and Groundwater	Mr. D. Daly	(Geological Survey)
3.45	Coffee		
4.15	Septic Tanks & Public Health	Ms. A. Deacon	(S.E. Health Board)
4.45	Septic Tanks and Groundwater - Some Recent Irish Research	Dr. R. Thorn	(Sligo R.T.C.)
5.15	Discussion		
5.30	Close		

Wednesday 8th April

9.30 a.m.	The Assessment of Groundwater Resources	Mr. G. Wright	(Geological Survey)
10.00	Groundwater Investigations in Sandstone Aquifers in N. Cork	Mr. P. Walsh	(Cork Co. Council)
10.30	Groundwater Investigations	Mr. K. O'Dwyer	(K.T.Cullen & Co.)
11.00	Discussion		
11.15	Coffee		
11.45	Groundwater Development Overseas		
	Introduction	Dr. D. Burdon	(Minerex Ltd.)
	Lesotho	Mr. S. Peel	(Minerex Ltd.)
	Mali	Mr. D. Ball	(E.R.A. Ltd.)
	Sudan and Senegal	Mr. G. Wright	(Geological Survey)
1.00 p.m.	Discussion and Close		
1.15 p.m.	Lunch		

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH GROUP)

7th Annual Groundwater Seminar, Killeshin Hotel, Portlaoise, 7/8 April 1987

LIST OF PARTICIPANTS

Aldwell, Bob	Geological Survey of Ireland, Dublin.
Ball, David	Environmental Resources Analysis Ltd., Dublin.
Bennett, Peter	Geological Survey of Northern Ireland, Belfast.
Brady, Eugene	Sligo Regional Technical College.
Burdon, Dr. David	Minerex Ltd., Dublin.
Carey, Tom	Kerry County Council.
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Collins, M.	Dept. of the Environment (Group Schemes).
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Connell, Tom	Well-driller, Blackrock, Co. Dublin.
Connor, Brian	Geoex Ltd., Tramore, Co. Waterford.
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Coyle, Fergus	Monaghan County Council.
Creegan, Jack	Laois County Council.
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Crowe, P.	Tipperary (N.Riding) County Council.
Cullen, Kevin	Cullen & Company, Consultants, Dublin.
Cullinan, Daragh	Longford County Council.
Daly, Donal	Geological Survey of Ireland, Dublin.
Daly, Owen	An Foras Taluntais, Dublin.
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Dunne, John	Dunnes Welldrilling, Mallow, Co. Cork.
Dunne, Paddy	Dunnes Water Services, Dromiskin, Dundalk.
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Forde, Gerry	Wexford County Council.
Furey, F.	Dept. of the Environment (Group Schemes).
Galvin, Gerard	Nicholas O'Dwyer & Partners, Dublin.
Galvin, Liam	An Foras Taluntais, Dublin.
Garrick, Michael	P.J.Tobin & Co., Castlebar.
Geraghty, Tom	Dept. of the Environment (Group Schemes)
Gibson, Gerry	Laois County Council.
Gordon, Douglas	Aquadrill Ltd., Dublin.
Hand, Michael	P.H.McCarthy Son & Partners, Dublin.
Harrington, David	Wicklow County Council.
Henry, Hubert	Sligo Regional Technical College.
Higginson, John	Carlow County Council.
Johnston, Paul	University College Galway.
Keane, Stephen	Murphy Engineers Ltd., Dublin.
Kelly, Larry	An Foras Forbatha, Dublin.
Kelly, Tom	Consultant, Dun Laoghaire.
Keohane, Jer	Water Research Centre, England.
Kilgarriff, Thomas	Cavan County Council.
Lane, Tony	Computing Techniques (MFG) Ltd., England.
McCabe, Gerald	South Eastern Health Board, Waterford.
McCarthy, Denis	Waterford County Council.
McEvoy, Harry	Dept. of Agriculture (Land Commission), Dublin.

McLoughlin, G.	Dept. of the Environment (Group Schemes).
McMahon, Dr. Emmet	Institute for Industrial Research & Standards, Dublin.
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Marron, Donal	K.T.Cullen & Co., Dublin.
Monahan, Frank	Galway County Council.
Moore, David	Dept. of the Environment, Dublin.
Mulqueen, John	An Foras Taluntais, Creagh, Co. Mayo.
Mullins, Sean	Laois County Council.
Murnane, Con	Meath County Council.
Murphy, J.M.	Kildare County Council.
Naughton, Breda	An Foras Forbatha, Dublin.
O'Donohoe, Denis	O'Donohoe Brothers, Well-drillers, Gorey, Co. Wexford.
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O'Rourke, Donal	Sligo County Council.
O'Rourke, Hilary	South Eastern Health Board, Wexford.
Otten, Almar	An Foras Taluntais, Creagh, Co. Mayo.
Peel, Stephen	Minerex Ltd., Dublin.
Phelan, Pat	Leitrim County Council.
Scott, William	Kilkenny County Council
Shallow, Joe	Clare County Council.
Skinner, Dr. Andrew	Severn-Trent Water Authority, England.
Smyth, William	Geological Survey of Northern Ireland, Belfast.
Sweeney, Niall	Offaly County Council.
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Walsh, Paul	Cork County Council.
Warke, Geoff	Geological Survey of Northern Ireland, Belfast.
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Gerard O'Leary
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Martina Lavin
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7TH ANNUAL GROUNDWATER SEMINAR

PORTLAOISE, 6TH-7TH APRIL 1987

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PAPER: "POLICY FOR AQUIFER PROTECTION"

by

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7th Groundwater Seminar, Portlaoise, 6th-7th April 1987

POLICY FOR AQUIFER PROTECTION

Andrew Skinner, Severn-Trent Water Authority, U.K.

WHY AQUIFER PROTECTION?

Groundwater is an important natural resource, and a resource in greater demand and subject to greater threat than ever before. It is hidden from view and its occurance and use are not widely understood. This lack of awareness is a worldwide problem and applies even in those countries where groundwater is virtually the only source of public supply. There is concern that this resource may only come to be fully appreciated when much has been lost through pollution and has had to be replaced by more expensive and often less satisfactory alternatives.

Groundwater is normally of very high quality and reliable in yield. In most circumstances it enjoys substantial natural quality protection and it is only very recently that the nature and intensity of human activity has been such that its quality has been significantly placed at risk. The importance of the quality of groundwater lies in its role not only as a source of public supply but also in maintaining the quality of surface water, to which it provides significant flow support, particularly in the summer months.

Auifers are areally extensive and not limited to confined channels like surface water. A wide range of potentially polluting activities can be carried out above, and even within, aquifers by persons who may be unaware of the risk their activities are posing for water resources. Planners, engineers and industrial plant managers are amoung the broad span of disciplines who need to be aware of the issue and, where relevant, act to minimise the threat of pollution.

Water flow in aquifers takes place orders of magnitude more slowly than in surface waters. In addition the pollution of groundwater is not readily subject to the same regenerative processes that can take place in rivers. These factors mean that groundwater pollution, once it has occurred, dissipates very slowly indeed and frequently the rehabilitation of polluted aquifers is not a realistic option. In groundwater pollution control prevention is paramount, since a cure may not be technically or economically viable.

The quality of groundwater is thus important and its preservation depends upon reducing pollution to a minimum. This can be done by exploiting any natural geological protection and, where possible, by directing potentially polluting activities to low risk areas. Otherwise the activity must be curtailed or only carried out with adequate safeguards. These controls cannot be achieved unless there are generally accepted and universally applied procedures or rules for aquifer protection.

APPROACHES TO AQUIFER PROTECTION

There are two basic approaches to aquifer protection which have been adopted in varying forms in most developed countries. One approach, which is applied when groundwater protection is well established in the national legal code, relies on statutory procedures to define restrictions on activities close to water supply sources. The restrictions are classified by zones, which are areas of land around boreholes defined on the basis of travel times for non-dispersive flow in saturated media. The zones rarely extend beyond 2km radial distance from the source and aquifers beyond this distance may have no controls imposed on them. Table 1 shows, in a broadly comparable form, the schemes of aquifer protection adopted in a variety of European countries. The statutory approach is widely used in continental Europe, although it has a number of drawbacks. The main problems are:

1) the system is not flexible to take account of changed circumstances or new technical information and the zones can only be modified by time consuming study;

2) the zones are centred on existing sources of water supply and so only protect these and not the complete groundwater resource;

3) the approach is based on prohibition and thus does not make a positive contribution to planning studies where the overall best practical environmental option is sought;

4) the considerable technical effort required to define the protection areas with the necessary precision is a responsibility of the water supply agency; this is contrary to the Polluter Pays Principle which would allocate the cost to the initiator of a pollution threat.

5) zone definitions are generally based on the travel time concept and thus they relate primarily to degradeable point source pollutants and not diffuse pollutants.

The statutory approach has stood the test of time and the problems mentioned above have not provided a significant obstacle, particularly in the high porosity, shallow water table, granular aquifers where the approach evolved in the Netherlands and northern Germany. This is because in this type of hydrogeological environment the zones are small and relatively easy to define. The concepts do not, however, transfer so satisfactorily to more varied hydrogeological environments and are particularly inappropriate in fissured and karstic aquifers.

A different approach to groundwater protection is to use the concept of groundwater vulnerability, and to classify aquifers in terms of the perceived risk, depending on their type and the nature of their natural quality protection. The classification covers the whole of the aquifer area and does not relate only to public sources. The results of a vulnerability asessment are normally clearly displayed in map form and this makes the information they contain widely accessible. Vulnerability assessments are good for identifying options and they provide a positive contribution to multi-objective planning. They do not, by themselves, provide a system of aquifer protection and they need to be linked to a code of practice if used for this purpose. This is the approach which has evolved in the U.K. where, as can be seen from Table 1, the procedures contrast strongly with other countries in Europe. The prime responsibility for groundwater protection lies with the multifunctional Water Authorities and some, including Severn-Trent, have developed Aquifer Protection Policies with related maps to provide the framework for groundwater quality control.

Prohibitions	Fed. Rep. Germany	Austria	Belgium	Finland	The Netherlands	France	Switzerland	Czechoslovakia	Hungary	Sweden	Great Britain
Only Water supply activities allowed	Zone I Well field 10 m	Immediate Protection area	Immediate Protection zone	Intake area ????	Well field	Immediate protection (10 à 20 m)	zone I 10 — 20 m	First sanitary production zone 10 — 50 m	Protection zone	Well area	Immediate non-statutory protection area (normally 10-50 m)
Prohibition on building Agricultural restrictions	Zone II 50 days	Protection area 50 days	100 m 24 hrs. Inner protection area (300-1000 m) 50 days	Inner protection zone 60 days	Catchment area (> 30 m) 50 à 60 days)	Inner protection area ????	zone II 10 days ≥ 100 m	Internal second sanitary protection zone ????	50 days ???	Inner protection area ≥ 60 days ≥ 100m	no fixed zones but groundwater protection achieved through consultation under statutory development planning and environmental control procedures with priority to aquifer recharge areas (Vulnerability classifications may be used as tools in this process)
Restrictions on certain industries, storage and transport of certain chemicals and oil	Zone III A 2 km	Partial protection area	Remote protection area	Outer protection zone	Protection area 10 years delay Protection area 25 years delay	Remote protection area	zone III ≥ 200 m zone A	External second sanitary protection zone	hydro geological protection area 25-100 year delay	Outer protection area	
	Zone III B				Far recharge area		zone B		regional protection		

OUTER BOUNDARY OF RECHARGE AREA

SCHEMATIC COMPARISON OF EUROPEAN PROTECTION POLICIES - from Van Waegeningh, included in reference 9.

TABLE 1

OBJECTIVES OF AN AQUIFER PROTECTION POLICY

There cannot be a standard blueprint for aquifer protection since much will depend upon the existing legal code, the hydrogeological environment and the types of pollution risk in the country in question. It is possible, however, to establish a set of objectives which a policy should seek to fulfill, and the following list is proposed in this context:

1) it should provide effective control of pollution and emphasise prevention rather than cure;

2) it should ensure uniform standards of practice and a consistent approach in dealing with similar situations across the region;

3) it should encourage good practice and contribute to the selection of the optimum environmental solution;

4) it should be cost-efficient in its application and direct the use of the available technical resources to the key problem areas;

5) it should apply not only to the protection of groundwater in existing use but preserve the quality of resources for the future;

6) it should be suitable for all types of potential pollutants, diffuse as well as point source, conservative as well as degradeable;

7) it should encourage the application of the Polluter Pays Principle and not place the onus on the user of groundwater to prove that his source will be threatened.

The scope of this paper is to describe, in the context of the above objectives, the situation in the UK and specifically in the Severn-Trent area, and to consider how far the above objectives have been met. This is intended to be a practical guide to help others to to decide whether a similar approach would be approriate in their own situation. Four appendices are included:

* a reference list of recent publications on the topic;
* a summary of the scope of the 1987 revision of the Severn-Trent Aquifer Protection Policy
* the conclusions of a recent workshop on the topic of Groundwater Protection Policy and Management organised by the European Institute for Water in association with the International Association of Hydrogeologists in Strasbourg is March 1986;
* an extract from a US EPA report which summarises the form of groundwater protection strategy now being implemented in the USA.

EUROPEAN LEGISLATION

The EC Directive (80/68/EEC) on "The protection of groundwater against pollution caused by certain dangerous substances" is the only instrument of European Legislation directly relevant to groundwater protection. It is a subsiduary directive to the Dangerous Substances Directive and is designed to place controls on the discharge of certain substances to the groundwater environment. These substances are specified in two lists; List I which includes certain organic compounds, cyanides, hydrocarbons and compounds of mercury and cadmium and List II which includes most other metals, biocides, phosphorus fluorides, ammonia and nitrites. Member countries are required to provide means whereby the introduction of List I substances is prevented and the introduction of List II substances is limited so as to avoid pollution. Most groundwater pollution incidents involve listed substances and so this directive provides a firm European wide basis for groundwater protection. It is open to doubt whether the organisations in each country responsible for the implementation of the directive, the so-called "competent authority", actually understand the scope of activities which might need to be controlled. The one major groundwater pollutant which falls outside the scope of the directive is nitrate.

UK LEGISLATION

The main piece of legislation in the UK relevant to the control of groundwater pollution is the Control of Pollution Act, 1974. This Act was a significant advance on previous legislation which had not given specific recognition to groundwater pollution and had excluded many activities from control. The situation is still not ideal, in that groundwater pollution is controlled under the Act in two different ways and by two different agencies, and the Act does not cover all activities which might give rise to groundwater pollution.

Control of Pollution Act Part I

This part of the Act deals with the disposal of waste to land. The protection of water resources is thus only one of the many relevant issues. All sites for the disposal of "controlled waste", which covers most polluting wastes, must be licensed under the Act. The licensing authority is the County Council (or District Council in Wales and the Metropolitain areas), but they may not issue a licence unless it is approved or contains conditions requested by the Water Authority. There is an appeal procedure in the event of irreconcilable disagreement between the two bodies. This Act is the only means by which groundwater pollution from landfill leachates may be controlled; the possession of a licence for a landfill and compliance with its conditions is a defence against prosection for water pollution under Part II of the Act.

Control of Pollution Act Part II

This part of the Act deals with the pollution of all water, including groundwater. Discharges which are not authorised by a Water Authority and which cause or are likely to cause pollution are an offence. Discharge consents are required for all direct discharges to groundwater and for all indirect discharges of trade and sewage effluent. The terms "indirect" and "direct" discharge do not come from UK legislation but are those used in the EC Directive to mean discharges respectively with or without percolation through ground or subsoil.

Other relevant legislation

Some potentially polluting activities, particularly those arising from quarrying and mining, do not come within the scope of either of the above and may only be restricted by appropriate conditions under the planning laws. These are the reponsibility of either the County or District Council. There is no obligation on these bodies to include restrictions for protection of water resource sought by water authorities, although they generally comply. The problem is to ensure that the planners perceive the possible problems and consult at the appropriate time so that any necessary control can be identified.

Another important role for planning legislation is the the long term protection of the environment from landfills after waste disposal has ceased. Under present UK legislation the landfill licence, and thus all the obligations which it includes, can be surrendered at any time. This means that the landfill licence is not the appropriate place to include any conditions, designed to ensure the long term integrity of the landfill, which need to be enforced after landfill operations have ceased. These responsibilities are therefore included in the planning consents issued for the landfill sites. This is an unsatisfactory and not always effective procedure and there are current proposals to modify the Control of Pollution Act to include long term controls as part of the landfill licence.

There are many other laws which have some relevance to groundwater pollution control. The Pipeline Act is an example. This provides a procedure whereby companies wishing to build cross country pipelines, for example to carry petroleum from refinery to inland depot, can obtain powers to construct. Water Authorities have the right to object to locations which they believe pose a threat to their interest. This procedure can and has been used to require a change of route to a more acceptable location when water supplies were considered to be threatened.

SEVERN-TRENT'S AQUIFER PROTECTION POLICY

The impetus for establishing the Severn-Trent aquifer protection policy was the need to try and achieve a consistent framework for the assessment of pollution risk which could be used in the range of different statutory and liaison procedures. In the UK, as a matter of routine, the Water Authority has to liaise in groundwater protection matters with the Waste Disposal Authority and the Planning Authority (which may be separate departments of the County Council or may be separate bodies), with waste disposal contractors and their consultants and with local public interest groups. Depending on the nature of the consultation a number of individuals from the Water Authority may be involved at local and regional level. In the interests of consistency and efficiency it is necessary that all these discussions, both informal and formal, should take place on a consistent basis. At the time when the policy was introduced, in 1976, there was only a limited appreciation of hydrogeological factors influencing planning and waste disposal decisions and very few local authorities employed hydrogeologists or retained suitable consultants. There is no doubt that the Severn-Trent policy and its supporting maps, which wer made readily available to all County and District Councils, made a significant contribution in achieving a consistent, and thus respected, approach and also helped to advance understanding of the hydrogeological constraints at that time. Over the past eleven years the waste disposal industry has become technically more sophisticated and the "educational" role of the policy is now not so important. None the less the benefits to be had from a systematic and widely understood approach are still very evident. It is significant that, of the more than 2000 consulations which Severn-Trent have dealt with under the Control of Pollution Act since 1976, only six have had to go to appeal before the Secretary of State. All of these appeals have been determined in Severn-Trent's favour.

STRUCTURE OF THE POLICY

The policy establishes four aquifer zones covering the whole of the catchment area. Zone 2 covers the outcrop of the major aquifers, the Triassic sandstones, the Magnesian Limestone and the Carboniferous Limestone, which together make up some 25% of the Severn-Trent area. Zone 3 covers the minor aquifers, that is those which are normaly only used for local domestic or agricultural supplies. Zone 4 covers those areas where the strata present are not normally regarded as aquifers at all and at best only provide small domestic supplies or where the aquifers are confined beneath impermeable strata. For each of these zones, which are defined on purely geological criteria, the policy identifies the activities which the Authority would view with concern and would normally oppose or only approve if suitable protective measures are incorporated.

The scale of the restrictions sought reduces substantially from Zone 2 to Zone 4. In Zone 4 the risks to groundwater are very few and in most circumstances Severn-Trent would prefer to see waste disposal activities concentratated in such areas, subject to the satisfactory protection of surface waters which is likely to be the greater risk in such situations. The highest degree of protection is reserved for Zone 1, which is not geologically based, but is a one kilometre radius circle around the major water supply sources.

The zone 1 area is not defined on the basis of a specific travel time, as in the case of European statutory protection zones, since it was not considered approriate to devote the investigative effort to devise such precise areas for all of the 350 public water supply sources within the Authority's area. It is drawn as a conservative zone which is likely to encompass all areas which could give rise to a pollution risk, in the knowledge that any potentially polluting activity within that area would have to be rigorously investigated before it could be agreed.

More recently two subdivisions of Zone 1 have been added to the Policy. The first of these only concerns the public water supply sources operated by the Authority and is designed to provide a higher degree of security to its own activities within the operational land area. It establishes, for example, standard practices for the construction of borehole headworks chambers and for the storage of oil and bulk chemicals at borehole sites. The area of the operational land will vary with individual circumstances but will not be less than 25 metres radius. Other organisations operating groundwater sources are advised to take similar precautions, but these are a matter of their own responsibility since generally it is only their own assets which are at risk.

The second addition is to include an inner zone, called zone 1A, of typically 200 metres radius, to specifically protect against bacteriological contaminants, of which the most important are agricultural slurries and domestic septic tanks. For degradable pollutants of this type, disposed of at or near to the land surface the thickness of the unsaturated zone is a significant factor in providing geological protection and this should ideally be taken into account in assessing the protection zone radius.

A "Code of Good Agricultural Practice" has been established by the Ministry of Agriculture as part of the provisions of the Control of Pollution Act. This code, if it is followed, provides a defence against prosecution under the Act. Water Authorities may establish zones of protection within which slurrying and manuring would not be regarded as "Good Agricultural Practice". Severn-Trent will be using the Zone 1A category to define the zones for this purpose

THE POLICY AS A TOOL IN PLANNING

The supporting maps to the policy, showing Zones 1 to 4 are prepared at a scale of 1:50,000 and are kept regularly updated. New public supply sources, as soon as they have been identified as potential future sites, and before they have been authorised for use, are included as additional Zone 1 areas. On rare occasions when revised geological data becomes available it may be necessary to revise other zone boundaries. The maps are made available free to all public authorities and at their reproduction cost to commercial organisations. They are widely used by these bodies for planning purposes.

All Waste Disposal Authorities are required to produce a Waste Dispoal Plan to identify for their area the future strategy for waste disposal. This is open to public scrutiny and comment and it is clearly valuable for those who prepare the plan and those who have to consider it that they have available an assessment of the relative merits of possible alternative waste disposal sites in water pollution terms. The Aquifer Protection Policy maps provide this at the initial level of identifying options. If it is necessary to make a more detailed study, this can only be done by on-site investigation. If this effort can be limited to only the more viable options then the policy has served a purpose in efficiently directing these resources. Similar issues arise in the identification of sites for mineral extraction where the policy plays a role in the planning process. A further example is in emergency planning, particularly in relation to urgent action in event of spillages, where the maps provide a readily accessible indication of possible threat to water supplies at any given location.

CURRENT ISSUES IN AQUIFER PROTECTION

The following paragraphs deal with specific aspects of groundwater protection in order to illustrate the use of the policy and to highlight some of the current issues in the UK.

Landfill

The effect of over ten years of more systematic planning of landfills has been to reduce the number of suitable quarry sites. New mineral operations are planned with a consideration of restoration options. A limitation on the availability of relatively inert waste may be an obstacle to successful promotion of a new quarry site. This situation, which arises in part from the effective aplication of aquifer protection guidelines, has led to the increasing development of "super-landfills". These are large waste disposal sites, perhaps in Zone 2 areas, where, because of the scale of the operation and because of the increasing shortage of suitable sites, it is economic for the operator to undertake major engineering works to achieve site conditions so that a wide range of wastes can be deposited without risk of pollution. In some cases sites have been proposed which are entirely above ground and substantial clay retaining structures are necessary to maintain the integrity of the landfill. These developments are not opposed in principle by Water Authorities, since they prefer to have a lesser number of large but well maintained landfill sites rather than the proliferation of small, underfunded operations which were more typical ten years ago. It has proved relatively easy to agree suitable protective measures in such landfills designed to provide long term water protection. It has been less easy to establish satisfactory mechanisms for continuous inspection to ensure that the necessary standards of control exist throughout the life of the landfill and afterwards. which might be for periods in excess of 40 years. This is because, whilst the Water Authority has a close involvement in the conditions for the establishment of a landfill, it has no direct responsibility for the monitoring of the conditions thereafter. These are the responsibility fo the Waste Disposal Authority, who are the "competent authority" for the purposes of the EC Groundwater Directive. The effective implementation of the conditions to ensure continued protection of groundwater is the subject of current debate and is not covered adequately by the policy.

Other Point Source Pollution

Point source pollution, other than from landfills, is either of industrial or agricultural origin. The major industrial pollutants are oils and organic solvents. Recently there have been a disturbing number of incidents of pollution by both from factories, storage depots and airfields. Hospitals, a substantial user of solvent for dry cleaning, have also been the source of major pollution. Collectively these incidents give rise to considerable concern since they are usually catastrophic as far as the future use of the groundwater is concerned. The problems almost always arise from bad procedures in plant design and operation and are virtually impossible for a Water Authority to anticipate. In many cases incidents are not identified until long after they have occured and remedial action is no longer possible.

Major point source agricultural pollution incidents affecting groundwater, for example from silage or intensive livestock units, are rare. The major problem in rural communities is at the other end of the scale and relates to the consenting of septic tanks. The safe integration of water abstraction and sanitation is a worldwide problem and is often too lightly regarded in "developed" countries. The number of applications for discharge consent for septic tanks is such that it is not possible to carry out a sufficiently detailed examination in each case. Priority is given to the protection of public water supply sources through the Zone 1A criteria. Simple decision rules have been devised to assess the potential risk from septic tanks to domestic groundwater supplies to ensure that the available resources can be devoted to the greater potential problems. A major constraint is to identify the location of water supply wells requiring protection. If they are used for domestic purposes only, they do not require a licence and thus may not be officially recorded. A proposed revision of the Water Resources legislation is expected to establish a system of registration of such sources so that they may be more readily identified for this and other purposes.

Radioactive Wastes

Special legislation exists in the UK for radioactive waste. There is only one existing site, for low level waste, and the search for new sites is currently consuming considerable technical resources. This, and also the deep injection of more conventional wastes, are special issues with very limited current application in the UK. They do not fit easily in a more general purpose aquifer protection policy. Their existance has to be recognised however, and it is necessary to avoid the concept of "unregulated" strata on grounds of minimal water resource interest, lest this compromises the control of disposal of difficult wastes.

Nitrates and other agricultural diffuse pollutants

Pollution of groundwater by nitrate leached from agricultural soils is a significant problem in parts of the UK including Severn-Trent and is likely to increase in the future. The problem is greatest in the intensive arable cultivation in the dryer eastern part of the country and its significance diminishes westwards by virtue of the higher effective rainfall and more diverse agriculture. For this reason the problem is unlikely to be significant in much of Ireland. The issue does however highlight the very different circumstances which prevail for the protection of aquifers from diffuse pollutants. It seems that any protection policy which is developed will have to depend on zones of legally enforcible prohibition of certain types of agriculture. The current revision of the Severn-Trent policy anticipates this possibility, but, as yet, no formal moves to seek powers under the Control of Pollution Act have been made.

The impact of dispersed agricultural pollutants on groundwater depends upon the degree of natural protection available both from the soil and from any overlying deposits. An exercise is currently in progress to improve the mapping of vulnerability in the Zone 1 and Zone 2 areas of Severn-Trent by combining soil and geological information. These maps will be used to enhance the use of the aquifer protection policy and to help publicise the location of vulnerable aquifers to the agricultural community. Although these maps have been prepared primarily to deal with the nitrate problem, they are relevant to other types of diffuse pollutant, for example agricultural biocides. These have been found locally in some groundwaters in UK and may prove an increasing problem in the future.

ROLE OF THE HYDROGEOLOGIST

Groundwater protection based upon vulnerability assessment is less rigid and more capable of adaption to individual circumstances than a system based on pre-defined statutory restrictions. Properly used this is a great advantage. However the vulnerability assessment is not something which can always be precisely determined in every situation at reasonable cost and it is necessary in some circumstances to rely on the judgement of an experienced professional. It is therefore essential that people with the relevant skills and experience, principally hydrogeologists, but also chemists and soil scientists, are widely and regularly consulted in the preparation of vulnerability maps, the assessment of individual proposals and in the monitoring of performance. It should be noted that the EC Groundwater Directive specifically requires that hydrogeological investigations be carried out before potentially polluting activities are sanctioned and that details of the results of these investigations are recorded by the "competent authority". The Commission have indicated that they will periodically review the application of this part of the Directive.

CONCLUSIONS

The experience in Severn-Trent and other UK Water Authorities over the past ten years suggests that a system of groundwater protection based on vulnerability maps which link to the national statutory controls through a formal Aquifer Protection Policy is a successful formula.

The areas where this approach has been most effective are:

1) ensuring uniform standards and directing potentially polluting activities to safer areas;

2) establishing and publicising the hydrogeological constraints;

3) encouraging adequate investigation and the use of hydrogeological and other relevant specialists so that proposals are assessed on as sound a technical basis as possible;

4) providing a reasonably objective method of ensuring that due account is taken of the "water interest" in planning studies.

The areas where present policies are less effective and where futher effort is necessary are:

1) dealing with problems of diffuse pollution where there is no individual source to control;

2) coping with the problems of an operational rather than a planning nature, and ensuring that activities, once consented, are carried out in a safe manner.

Progress in these latter areas will not be achieved by rules and regulations alone. Problems are bound to continue, particularly in industry and agriculture, while the general level of public awareness of the need for groundwater protection continues to be so low. We should try harder to present these issues in a popular format as a positive step in fostering good practice. The Geological Survey of Ireland information circulars on groundwater pollution topics are excellent examples, which we could, with benefit, follow in the UK. I also commend for attention the European practice of putting up a standard sign around the periphery of water supply installations. These are useful in providing a visual warning to those whose activities may threaten water quality, but they also serve a useful publicity role in drawing public attention to the existance of borehole installations, which are, by their nature, otherwise very inconspicuous.

Better groundwater protection depends not only on laws but on information. In particular it requires better and more accessibl technical information for engineer and planners, and more effort bein given to the education of farmers, industrialists and the general public to emphasise the benefits o protecting groundwater quality.

APPENDIX 1 RECENT REFERENCES ON AQUIFER PROTECTION

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8. LEWIS W J, S S D FOSTER and B S DRASER, 1980. The risk of pollution by on-site sanitation in developing countries. Int. Ref. Centre for Waste Disposal (IRCWD) report 01/82.

9. MATTHESS G, S S D FOSTER and A C SKINNER(eds), 1985. Theoretical Background, Hydrogeology and Practice of Groundwater Protection Zones. International Contributions to Hydrogeology No. 6, Heise(Hannover)

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11. SCHENK V, 1983. Hydrochemical maps as basic information for the protection of groundwater. As ref 2, pp1193-1202.

12. SELBY K H and A C SKINNER, 1979. Aquifer protection in the Severn-Trent region - Policy and Practice. Journ. Inst. Wat. Poll. Control pp. 254-269.

13. VIERHUFF H, 1981. Classification of groundwater resources for regional planning with regard to their vulnerability to pollution. Symp. Quality of Groundwater, Nordwijkerhout, pp1101-1106.

14. VRBA J and E ROMIJN(eds), 1986. Impact of Agricultural Activities on Groundwater. International Contributions to Hydrogeology No. 5, Heise(Hannover)

Reference 9 contains a number of papers relevant to groundwater protection policy. The proceedings of the 19th IAH congress held in Karlovy Vary(CSSR) in September 1986 are due to be published shortly. The issue of groundwater protection, especially in relation to agricultural pollution, is dealt with in a number of papers.

APPENDIX 2 SEVERN-TRENT AQUIFER PROTECTION POLICY

Severn-Trent Aquifer Protection Poliicy (1987 revision)
Summary of contents

Introduction - objectives and method of implementation

Operational land - guidelines for definition of the maximum area of operational land around borehole sites and controls upon potentially polluting activities, such as storage of fuel oil, use of fertilisers and pesticides.

Zone 1A (inner protection zone for bacteriological protection) - definition of area, assessment of risk from septic tanks, agricultural slurries and manures.

Zone 1 - normally one kilometre radius around all public supply boreholes. Activities identified as subject to control are:
a) waste disposal sites;
b) substantial residential development not connected to public sewer;
c) industrial development involving production, storage or use of polluting materials;
d) intensive agricultural activities;
e) oil and gas pipelines and major foul sewers;
f) sewage or trade effluent treatment works;
g) excavations for minerals which require backfilling with imported materials or which extend to within 3 metres of the maximum height of the water table;
h) discharge of surface water run-off to the aquifer if there is risk of pollution to the surface water.

Zone 2 - outcrop of major aquifers; controls on a), c) and d) above unless adequate protective measures are provided.

Zone 3 - outcrop of minor aquifers; controls on a) c) and d) as above but less stringent unless in the vicinity of known private abstractions.

Zone 4 - no restrictions imposed on grounds of aquifer protection unless in the vicinity of known private abstractions. May be need for controls to protect contamination of surface water run-off.

Appendices

1. Procedures for preventitive surveillance
2. Internal(within STWA) procedures for consultation on groundwater protection
3. Guidelines for the assessment of septic tank soakaways
4. Sewage sluge spreading
5. Extension of the Policy to river catchments
6. Assessment of vulnerability using soil and geological data
7. Technical background to the inner protection zone
8. Summary of major legislation affecting groundwater pollution.

APPENDIX 3 CONCLUSIONS AND RECOMMENDATIONS OF A SEMINAR ON GROUNDWATER PROTECTION, POLICY AND MANAGEMENT ORGANISED BY THE EUROPEAN INSTITUTE FOR WATER IN COLLABORATION WITH IAH. 20-21 MARCH 1986.

CONCLUSIONS	RECOMMENDATIONS
<u>Policy and Legislation</u>	
1. In many countries groundwater protection is based on statutory requirements and is often selective in areas covered.	1. Groundwater protection should have regard to the assessment of vulnerability and should relate to the whole of the groundwater resource. Also, the unsaturated and saturated flow, fissured or granular aquifers and the use of a safety factor to allow for aquifer heterogeneity should be taken into account. Due consideration should be given to the possible contamination of groundwater by surface water-groundwater interactions.
2. Groundwater policies often only deal with restrictions and prohibitions.	2. Groundwater policies should be constructive in the sense that they also provide some guidance to those activities that are restricted or prohibited in protected areas.
3. Legislative tools, which are also applicable for protection purposes, have frequently existed for a long time.	3. Policies should be implemented that fully exploit existing legislation and regulations, while new and more adequate legislation should be developed at the same time.
4. Sometimes new economic activities get only sufficient attention in policy making after problems have emerged in practice.	4. The use of new products which may be harmful to the groundwater quality shall be prohibited until the manufacturer has demonstrated its safety.
<u>Planning and Management</u>	
5. Prior to the emergence in practice of groundwater quality problems there is often a lack of awareness of potentially conflicting interests.	5. The management of aquifers in the widest sense should have regard to the conflict of interests which can arise between competing activities.
6. The protection of groundwater is a multi-dimensional issue with many different relations to social and economic activities.	6. Groundwater protection should be seen as being part of integral aspect planning, involving also physical or land use planning, water management, environmental management and natural resources management. Furthermore, special attention should be paid to the consistency of policies regarding agriculture, industry and socio-economic developments, with the groundwater protection policy.
. Risk analysis is part of groundwater management.	7. Risk analysis methods and risk management approaches should be further developed and applied.

Knowledge and Research

8. There is a lack of knowledge about underground physical, chemical and biological processes and changes in substances.

8. The behaviour of substances in the subsoil should be investigated with regard to their impact on groundwater quality.

9. The concept of zoning based on travel time is usually not adequate for diffuse, non degradable contaminants.

9. The principle of travel time to determine the protection zone should be critically revised in the case of diffuse, non degradable contaminants.

10. There is no international agreement on protection zone measures for groundwater sources that give a complete safeguard against contamination by microbes.

10. A standard or common travel time basis for microbial protection of public water supply sources should be adopted.

11. Research on groundwater protection has not always a practical value, while some research issues emerging from practical management get no follow-up.

11. Closer links and collaboration should be established between practical requirements for research results in the area of aquifer protection and the research programmes of scientific institutes.

12. Assessment of the vulnerability of soil and groundwater is essential for the implementation of groundwater protection policy.

12. Criteria should be established to quantify vulnerability and methods have to be developed to set up systematic procedures for the assessment of the vulnerability.

13. There is a lack of knowledge on trends in changes of groundwater quality.

13. Research should be done on the optimization of monitoring systems. Monitoring systems should be installed in order to measure changes in groundwater quality parameters in time and to facilitate explanation and prediction of these changes. Furthermore techniques should be developed to predict future changes in groundwater quality and to evaluate (alternative) protection policies and land use plans with respect to groundwater quality.

Information and Education

14. The value of uncontaminated groundwater is not widely and actively understood.

14. Public awareness programmes should be initiated to inform the public and the politicians on the importance of maintaining a high groundwater quality. Special attention should be paid to an individual approach of land users in protection zones.

15. There is a lack of awareness of the impact of environmentally harmful activities by those who are responsible for or execute these activities.

15. Information and education programmes should be developed for the originators of diffuse sources of pollution, especially farmers.

Economics and finance

16. The allocation of costs for protection of groundwater gives rise to financial unclarities and problems e.g. with regard to compensation of damage caused by pollution or compensation for revocation of licences.

16. Charging principles should be clearly defined and regulatory measures should be better combined with financial incentives and disincentives.

17. To meet the costs of environmental protection measures three charging principles could apply: polluter pays principle, user pays principle and public pays principle.

17. Priority must be given to the polluter pays principle.

18. There are circumstances where the polluter pays principle can not be carried out (due to lack of evidence and possible political, economic and social reasons).

18. Methods and techniques should be developed to reduce the number of circumstances which violate the polluter pays principle.

19. Economic principles do not work in the case of fertilizing in agriculture.

19. The use of fertilizers and biocides should be based on environmental standards and not on economic criteria.

APPENDIX 4 SUMMARY OF THE UNITED STATES ENVIRONMENTAL PROTECTION AGENCY STATEMENT ON GROUNDWATER PROTECTION STRATEGY, 1984.

EPA's Ground-Water Protection Strategy

EPA's Ground-Water Protection Strategy, issued in August 1984, sets forth the Agency's policy framework for ground-water protection in all programs, including pesticides. To foster implementation of the Strategy, EPA established a new Office of Ground-Water Protection in Headquarters and ground-water offices in each of the 10 EPA Regions.

Central to the strategy is a differential protection policy designed to ensure a level of protection that is appropriate to the use, value, and vulnerability of the ground water. The most stringent protection requirements apply in areas where the ground water is both highly vulnerable to contamination and either an irreplaceable source of drinking water or ecologically vital (Class I). The vast majority of the nation's ground water will be in Class II, where the water is a current or potential source of drinking water or has other beneficial uses (such as for irrigation). In these areas, "baseline" protection measures designed to reduce the risk of contamination apply. Ground water of little or no potential for future use because of natural or man-made contamination is defined as Class III. Here, some relaxation of baseline requirements might be allowed if the quality of the water is not harmful to human health or the environment.

To implement this policy, each EPA program that governs an activity affecting ground-water quality is devising management strategies to afford the appropriate level of protection to each class. These strategies may include such elements as siting criteria, engineering and performance standards, operating requirements, monitoring requirements, and best management practices.

A second major policy in the strategy acknowledges that States have primary responsibility for ground-water protection. EPA's role is to set national policy and standards and to provide the technical and other assistance needed by the States to improve State capacity to protect ground water. During FY 85 and FY 86, EPA provided $7 and $6.7 million, respectively, in Section 106 grants under the Clean Water Act to help the States develop and implement ground-water protection strategies.

All States are now in the process of developing and/or implementing strategies for ground-water protection. In addition to using the supplemental Section 106 grant funds to enhance interagency coordination on ground water issues generally -- including coordination with pesticide and agricultural agencies -- several States are using the funds for specific efforts to control pesticides in ground water. In FY 85, nine States used their grants to help assess the problem, develop monitoring strategies, and develop management alternatives for pesticides in ground water.

In addition to the State grant program, EPA has initiated several other actions to improve ground water protection efforts. The development of an Agricultural Chemicals in Ground Water Strategy represents a major step toward addressing a source of contamination which was identified in the EPA Ground-Water Protection Strategy as needing further attention. It also represents furtherance of another goal of the Strategy: to enhance coordination and cooperation between EPA programs which affect ground water.

A report on ground-water research prepared by a special EPA Science Advisory Panel includes recommendations for needed Agency research that can assist in addressing pesticide contamination problems. The Ground-Water Monitoring Strategy developed in 1985 includes actions to improve the quality, accessibility, and utility of all ground-water monitoring data, including data collected on pesticides.

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH GROUP)

SEVENTH ANNUAL GROUNDWATER SEMINAR

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AQUIFER PROTECTION POLICY IN IRELAND

- A CASE STUDY

BY

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1. Introduction

Since 1976 Tullamore Urban District Council has been investigating and proving the groundwater potential of the Clonaslee Sandstone Aquifer in County Laois. As a result of this work boreholes exist with a proven yield of 2270 m^3/d (500,000 g/d). It is proposed to harness these to augment existing supplies to Tullamore town and Contractors are presently moving onto site to carry out the required works.

The Clonaslee aquifer is a significant source of good quality potable water in a national as well as a regional context. It is also of vital importance to the continued development of Tullamore town as an industrial and commercial centre. Consequently, in January 1986 P.H. McCarthy Son & Partners were requested by Tullamore Urban District Council to make recommendations for the long-term protection of the aquifer from pollution. A draft Aquifer Protection Plan was submitted to the Urban Council in March 1986 as a basis for discussions with Laois County Council. A detailed Plan incorporating large scale maps of the proposed protected area was submitted to the Urban Council in May 1986. This Plan is presently being considered by Laois County Council with a view to its inclusion in the County Development Plan.

This paper outlines the development of the Plan and the basis for the aquifer protection policy. It also considers the problems in implementing and policing such a policy particularly outside ones own administrative area.

2. Origins of Aquifer Protection Plan

Since the drilling and testing of the boreholes the number of planning applications in the area of the wellfield was about 3 per year. Laois County Council had been alerted to the significance of the borehole scheme and had a policy of forwarding any applications in the vicinity of the borehole sites to Tullamore U.D.C. for their comments. However this proved difficult in the case of marginal type situations in so far that valuable time was lost in copying the application to the U.D.C. and in the absence of specific policy the Town Engineer would have to err on the side of safety and recommend refusal of applications close to boreholes. In early 1986 however one refusal on the grounds of protecting a borehole source was challenged by the applicant and with an appeal to An Bord Pleanala in the offing it was evident that a policy statement was necessary in order to afford protection to the aquifer. Also it was clear that such a policy should be founded on sound technical reasoning capable of withstanding courtroom type scrutiny. It is clearly preferable to prevent or reduce the risk of pollution rather than deal with its consequences. The main objective of the plan was to protect the aquifer while at the same time providing a planning tool to facilitate efficient administration of the planning function by Laois County Council.

During exploration chemical and bacteriological analyses showed no evidence of pollution of the aquifer. The nitrate levels recorded were always less than 2.0 mg/l (N). Using this parameter as an indicator of pollution it was decided to devise a plan which would ensure that the guide level of E.E.C. Directive 80/778 was not breached.

3. Wellfield Description

The wellfield is located in the Northern foothills of the Slieve Bloom Mountains, to the South East of Clonaslee. Figure 1 shows the relative locations of the four production boreholes, namely G, F, A and B. The proposed abstraction rates vary from 4.7 l/s to 10.7 l/s. The aquifer is part of Kiltorcan Aquifer System which extends all round Slieve Bloom. The geology and hydrogeology of the aquifer are only considered briefly here as these topics are dealt with in considerable detail in two reports by Mr. E. Daly of the G.S.I. The geological succession and other formation details in the area as described by Mr. Daly are as shown in Table 1.

AGE	FORMATION	LITHOLOGIES PRESENT	APPROXIMATE THICKNESS (m)
QUATERNARY	Unconsolidated Deposits	Till (boulder Clay) sands and gravels (varying clay content)	0 - 18
DINANTIAN	Ballymartin Point (or equiv.)	Fine grained limestones and mudstones	0 - 150
	Lower Limestone Shale (or equiv.)	Mudstones with thin limestones and sandstones at base	40 - 80
DEVONIAN	Clonaslee Flagstone	Sandstones and Mudstones	70 - 150
	Slieve Bloom Sandstone	Conglomerates, sandstones and siltstones	90 - 240
SILURIAN	Capard	Sandstones, siltstones and mudstones and minor conglomerates	1000 - 1500

Table 1. Geological succession in Slieve Bloom

The strata dip northwards at 10 - 20 deg. A number of faults with a N-S strike also traverse the wellfield area and the fracture zone associated with these contributes to borehole output. The uncolidated deposits vary considerably in thickness and up to 40% of the area has less than 5 m cover. However they consist mainly of till often underlain by sands and gravels.

Hydrogeologically, the waterbearing stratum is the Clonaslee Flagstone formation with relatively low transmissivities ranging from 20 to 90 m^2/d being recorded. The hydraulic conditions over the aquifer system in the Clonaslee area are considered to be quite varied. However the schematic representation in Figure 2 shows the general water movement pattern. Over most of the wellfield area the aquifer is considered to be confined and artesian conditions actually exist at three of the four production boreholes. The till or Lower Limestone Shale are the confining layer though they are considered vulnerable to leakage where the piezometric surface has been significantly lowered by pumping.

Recharge to the aquifer takes place where the overburden is less than 5 m thick or where sands and gravels exist. Under natural flow conditions the active groundwater moves Northwards. After the wellfield is put into production the cones of depression will be deep and narrow near each borehole and will have a shallow gradient at a distance. Pumping test data indicates that where the aquifer is confined the radius of influence of the individual production wells after a long non-recharge period could be in excess of 2 km. However at distances of 100 m and 1000 m the drawdowns resulting from the pumping of individual boreholes are likely to be less than 3 m and 1 m respectively. More accurate values for these distances, drawdowns and aquifer storage can only be obtained when the scheme is in operation and longer tests are performed with more detailed monitoring of water levels in the different wells.

4. Pollution Potential

The wellfield is an area of rolling countryside with moderate slopes. Most of the land has only moderate farming potential and a significant amount has been afforested. Present farming practices favour grazing with little dependence on tillage. The village of Clonaslee, with an approximate resident population of 350 persons, is located to the North West of the wellfield. Most houses in the village are connected to a public sewerage system. The sewage treatment works is situated some 0.75 km North of the village and treated effluent discharges into the Clodiagh River 0.25 km further North of this point.

The Link Road L116 traverses the North of the wellfield. Some ribbon development with septic tanks has taken place along this road both to the East and West of the village. Otherwise the area is characterised by isolated rural housing and farm buildings. There is no industrial development and only light commercial activity exists in Clonaslee.

The types of pollution which would limit the use of or render an aquifer unsuitable as a source of public supply are many and varied. In this wellfield bacteriological, viral, toxic, organic, nitrate and nitrite pollutants are most likely. The likely sources of these are:

* Sewage effluents from septic tanks, leaking cesspools, sewage treatment works, sewage sludge, leaky foul sewers and sewer overflows.

* Agricultural activities involving inorganic and organic fertilisers, animal wastes, agricultural chemicals and silage.

* Domestic and industrial waste disposal from landfill sites, lagoon storage, disused quarries, soakaways, deep and shallow wells.

* Surface drainage and accidental spillages from roads and road tankers, housing and industrial soakaways.

Apart from these more obvious sources four streams cross the wellfield area. Three of these flow close to boreholes and while not thought to be in continuity with the aquifer their quality must be preserved as a precaution.

5. Technical Basis of Policy

The cone of depression associated with the Clonaslee Wellfield is likely to be at least 6 km in length and vary in width from 1.5 - 2.5 km depending on the particular hydraulic conditions in the different areas. The area covered by the Plan is in excess of 14 sq. km.

The scheme proposed is based on the Aquifer Protection Policy developed by the Geological Survey of Ireland. The system of zones and the developments prohibited in each zone are in general the same in both except in this case the zones have been adjusted to reflect with the geology and hydrogeology.

As already stated the objective of this policy is to maintain the present excellent water quality in the aquifer. Using nitrate as an indicator and allowing a reasonable factor of safety the policy is designed to keep the nitrate levels in the abstracted water below 4.0 mg/l (N), viz doubling the existing levels. It is clear from the foregoing that many potential sources of pollution, particularly agricultural activities are diffuse. In order not to restrict the development of modern farming practices a 1.0 mg/l increase in nitrate level from diffuse sources is considered possible in the long-term.

Septic tanks are a major contributor of nitrate to groundwater. Studies by the G.S.I. have shown that in an area like Clonaslee where the effective recharge is 0.7 m/yr. the density of septic tanks should be less than 1/1.6 ha. (1/4 acres) if the background nitrate concentration is not to be increased by more than 1.0 mg/l (N). Also clustering of septic tanks is not recommended. It is these criteria which are used in the restrictions in Zone 1C.

The protection zones are shown on Figure 3 and are as follows:

<u>Zone 1</u> <u>Source Protection Zone</u>

Zone 1A The area within a 10 m radius of the source.

Zone 1B The area between 10 m and 100 m of the source. A distance of 100 m for the outer boundary of this zone has been chosen due to the presence of thick and relatively impermeable quaternary deposits which underlie most of the area and the fact that beyond this distance there is likely to be an upward pressure across the bedrock surface thereby inhibiting leakage through the confining layer. In the case of borehole B the outer limit of this zone is extended to 200 m as the depth of bedrock is less than 5 m thick over much of the area to the East of the borehole.

Zone 1C This zone extends from 100 - 1,000 m on the East, West and Southern sides of the wellfield. Where the aquifer is unconfined over a portion of the cone of depression the drawdown should be zero by 1,000 m. Where it is confined the drawdown should be less than 1 m but the aquifer should not be at risk owing to the upward water pressure and the thick quaternary deposits. As one proceeds North the 'sandstone' part of the aquifer system is overlain by a progressively thicker sequence of the Lower Limestone Shale which acts basically as an aquitard. Hence the boundary between this unit and the underlying Clonaslee Flagstone Formation is considered to be suitable as the outer limit of this zone along part of the northern side of the wellfield. In the case of three of the production boreholes this outer limit is at a distance of about 500 m. The fourth well, borehole F, penetrates over 45 m of the Lower Limestone Shale and 14 m of overburden above the sandstone. In this block the upper boundary of the 'shale' is suitable as the outer limit of this zone.

As the fracture zones associated with the faults crossing the wellfield are considered to be highly permeable it is felt that they require protection in zones 1B and 1C. Hence the outer limits, along the suggested location of these faults, have been increased by 50%.

Zone 2 Aquifer Protection Zone

This zone in general includes the area between the outer boundary of Zone 1C and the contact between Clonaslee Flagstone Formation and the Slieve Bloom Sandstone Formation South of the wellfield. Recharge in this area will move North and eventually flow into the wellfield area. That part of the Lower Limestone Shale Formation adjacent to the wellfield and not already included in Zone 1C also forms part of this zone.

Examples of detailed maps are attached as Figures 4 and 5.

6. Policy Statement

Controls are applied as follows:

Zone 1A Prohibit all activities having any potential to pollute.

Zone 1B Prohibit:

(i) The construction of houses with septic tanks.

(ii) The spreading of slurry and manure above A.C.O.T. recommended rates of application.

(iii) The spreading of sewage sludges.

(iv) The establishment of burial grounds.

(v) The use of lands as waste disposal sites.

(vi) Industrial developments involving the use, production and storage of potentially polluting substances.

(vii) Agricultural activities such as rearing or housing of poultry or livestock, the construction of slurry pits or lagoons and the construction of silage pits.

(viii) Dumping of farm chemicals such as insecticides and sheepdips.

(ix) The laying of foul sewers or house drains.

(x) The construction of sewage and trade effluent treatment works.

(xi) The construction of soakaways for surface or road drainage.

(xii) The use of land for mining or quarrying.

(xiii) The extraction of sand or gravel.

(xiv) Surface stream pollution.

Zone 1C Prohibit:

(i) The construction of houses with septic tanks except where the following criteria are complied with:

* The average septic tank density for the area is kept below 1/1.6 ha. (1/4 acres).

* The development does not constitute clustering.

* Individual sites have a minimum area of one acre.

* Septic tanks with appropriate percolating areas to be constructed in accordance with the I.I.R.S. publication S.R. 6:1975.

(ii) The use of lands for waste disposal sites.

(iii) Industrial developments except light industry without storage for significant quantities of oils, chemicals or fertilisers.

(iv) Intensive agricultural activities such as the intensive rearing of housing of poultry or livestock. Slurry pits, silage pits, lagoons allowable subject to strict control.

(v) Dumping of farm chemicals such as insecticides and sheepdips.

(vi) The laying of foul sewers and drains unless constructed of approved materials, in an approved manner.

(vii) The construction of sewage and trade effluent treatment effluent treatment works.

(viii) The use of land for mining or quarrying.

(ix) The extraction of sand or gravel.

(x) Surface stream pollution.

Zone 2 Prohibit:

(i) The use of lands for waste disposal sites intended to receive hazardous or toxic wastes.

(ii) Major industrial and agricultural developments which involve the use, storage or handling of toxic potentially polluting materials unless adequate protective measures are agreed.

7. Policy Implementation

There is no one piece of Irish leglislation empowering the local authority to control all the aforementioned activities. As such the implementation strategy in the case of the Clonaslee Wellfield incorporates the following elements:

(a) Local Government (Planning and Development) Act 1963

- Planning control of new developments.

(b) Local Government (Waste Pollution) Act 1977

- Control of polluting activities
- Water quality management plan

(c) Local Authority's Own Actions

- Care in selecting sites for burial grounds, waste disposal sites, gravel pits etc.

(d) Local Authority Major Emergency Plan

- Emergency plan for chemical spillages along route L 116

(e) Liaison with A.C.O.T.

- Advice to farmers on timing of fertiliser application

(f) Survey

- Identify and remedy existing offending developments

(g) Monitoring

- Water quality, water levels and pumping data collection

(h) Policy Review

- At three year intervals

The fact that the wellfield is in County Laois requires that Laois County Council be responsible for the thrust of the policy with occasional assistance from Tullamore U.D.C. More specifically with regard to (a), (b), (c) and (d) above Laois County Council have primary responsibility while only (g) is the full responsibility of Tullamore U.D.C. With regard to (f) some of this work is being carried out by Laois County Council under the Water Pollution Act while the more detailed work is being carried out by Tullamore U.D.C. in liaison with Loais County Council. A joint effort is also required for (e) and (h). It is evident that clear lines of communication are required between the two authorities if the objective of protecting the aquifer is to be achieved.

8. Other Issues

I believe that this plan is capable of dealing with the vast majority of hazards in the Clonaslee wellfield. The policy is founded on the best available geological and hydrogeological information available at the present time. However it is inevitable that marginal situations will arise and these will require more detailed study based on the latest available data prior to decision making.

An area of concern with aquifer protection plans such as this is their effect on community attitude and land acquisition practices. The imposition of development restrictions inevitably results in a reduction in potential land values or costlier developments when allowed. This will also present problems for water engineers in the procurement of suitable borehole sites. The control of diffuse sources of pollution, particularly agricultural wastes, will be difficult and the goodwill of the community is necessary in this regard. Difficulties in site acquisition can seriously damage community/local authority relationships to the ultimate detriment of the protection plan. Care needs to be taken in these situations and while I believe that the principles should be upheld I nonetheless urge valued judgement in the knowledge that the primary objective is affording the best possible protection to the aquifer.

Again, as in many previous papers on groundwater the need for good preliminary data supplemented by accurate operating data is evident. This data not only serves as a defense of the Plan but is also essential in subsequent strengthening or relaxing of controls in the light of pumping experience.

A further issue worth noting is the need to consider aquifer protection at the earliest possible stage of groundwater scheme planning. Aquifer vulnerability should be determined so that the lead-in time to aquifer pumping can be used to control undesirable development and also to carry out remedial works on existing hazards. Such remedial works might include the piping of septic tank effluent to a percolation area outside Zone 1B, the extension of public sewerage to pick-up ribbon development or the use of Orders under The Pollution Act to eliminate obvious pollution situations.

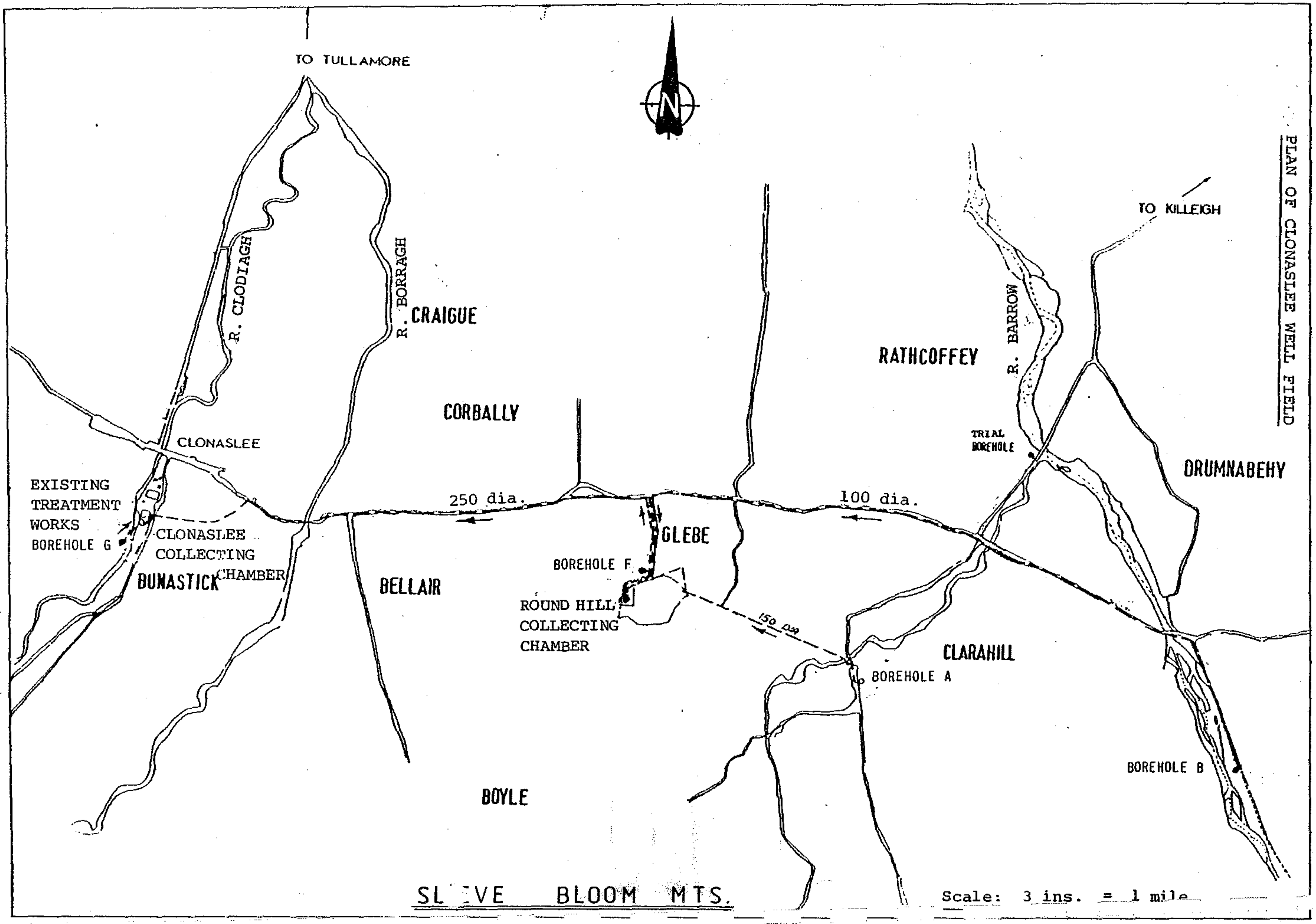
9. Conclusions

The United States and European Countries are presently experiencing major groundwater pollution problems and very expensive remedial action is now being taken. In Ireland we are fortunate that major aquifer pollution has not arisen to date. The Clonaslee aquifer is an example of an excellent groundwater source. The primary objective of Tullamore U.D.C. is to prevent the creation of pollution or nuisance at source rather than subsequently trying to counteract their effects. The Aquifer Protection Plan as detailed allows for doubling of the pollution loads while still complying with relevant E.E.E. Guide levels. Provision has been made for a periodic review of the policy as required.

10. Acknowledgements

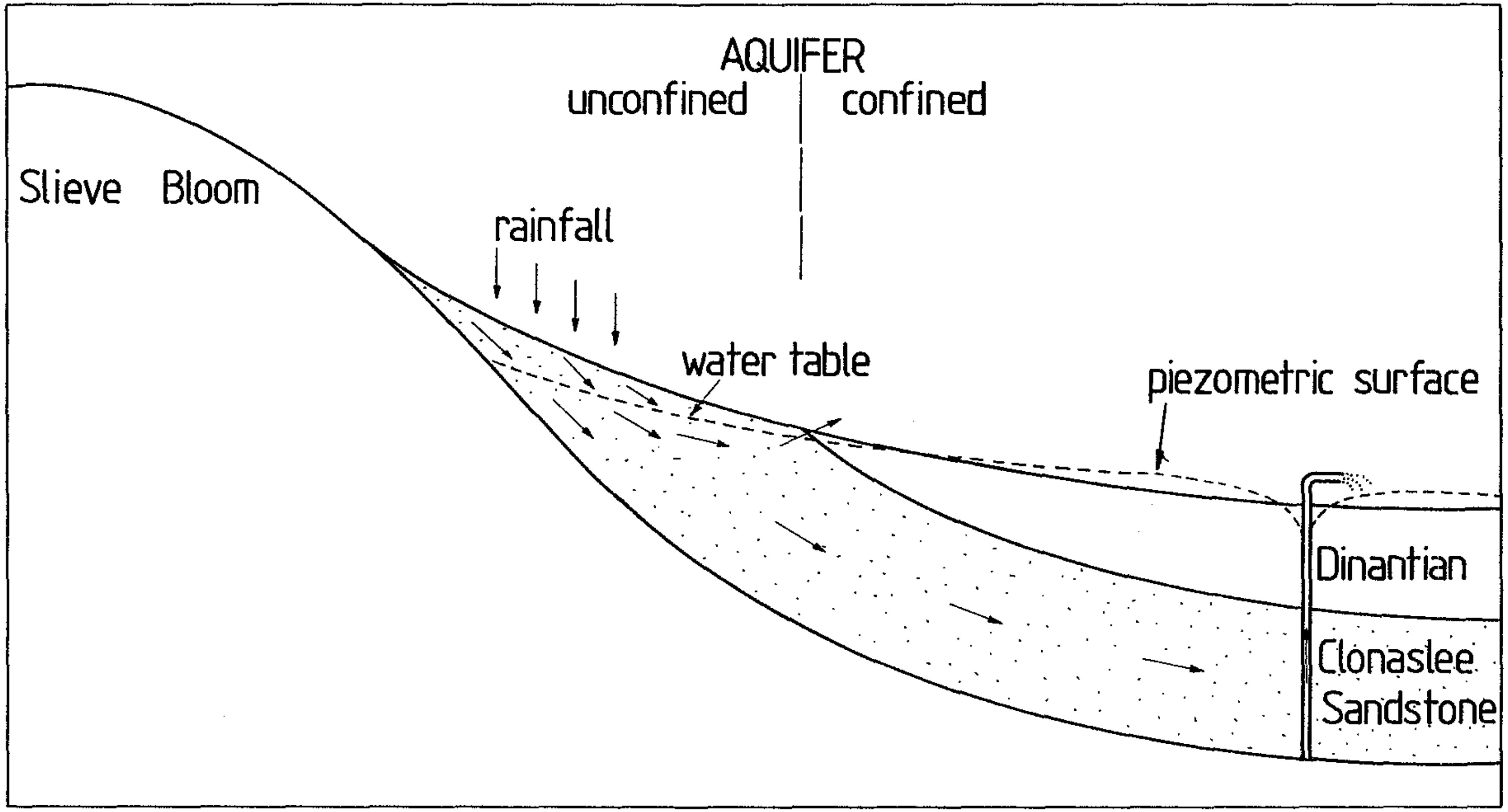
The Author wishes to thank Tullamore Urban District Council and P.H. McCarthy Son & Partners for permission to present this paper.

I would also like to acknowledge the assistance of the G.S.I. and in particular Mr. E. Daly, in the preparation of the Plan for Clonaslee wellfield.



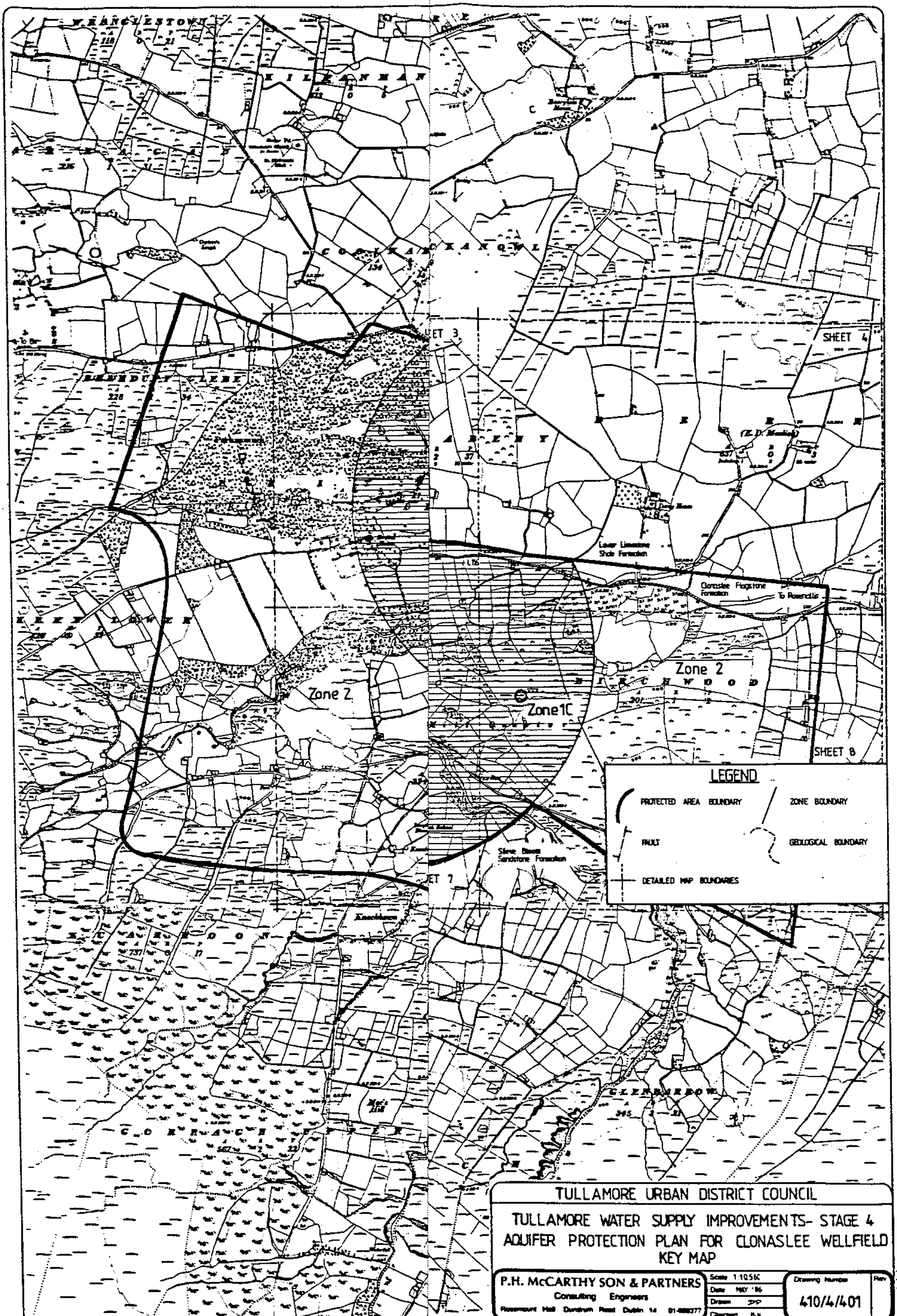
PLAN OF CLONASLEE WELL FIELD

Fig. 1



Schematic representation of groundwater movement in the Clonaslee Sandstone

Fig. 2



TULLAMORE URBAN DISTRICT COUNCIL

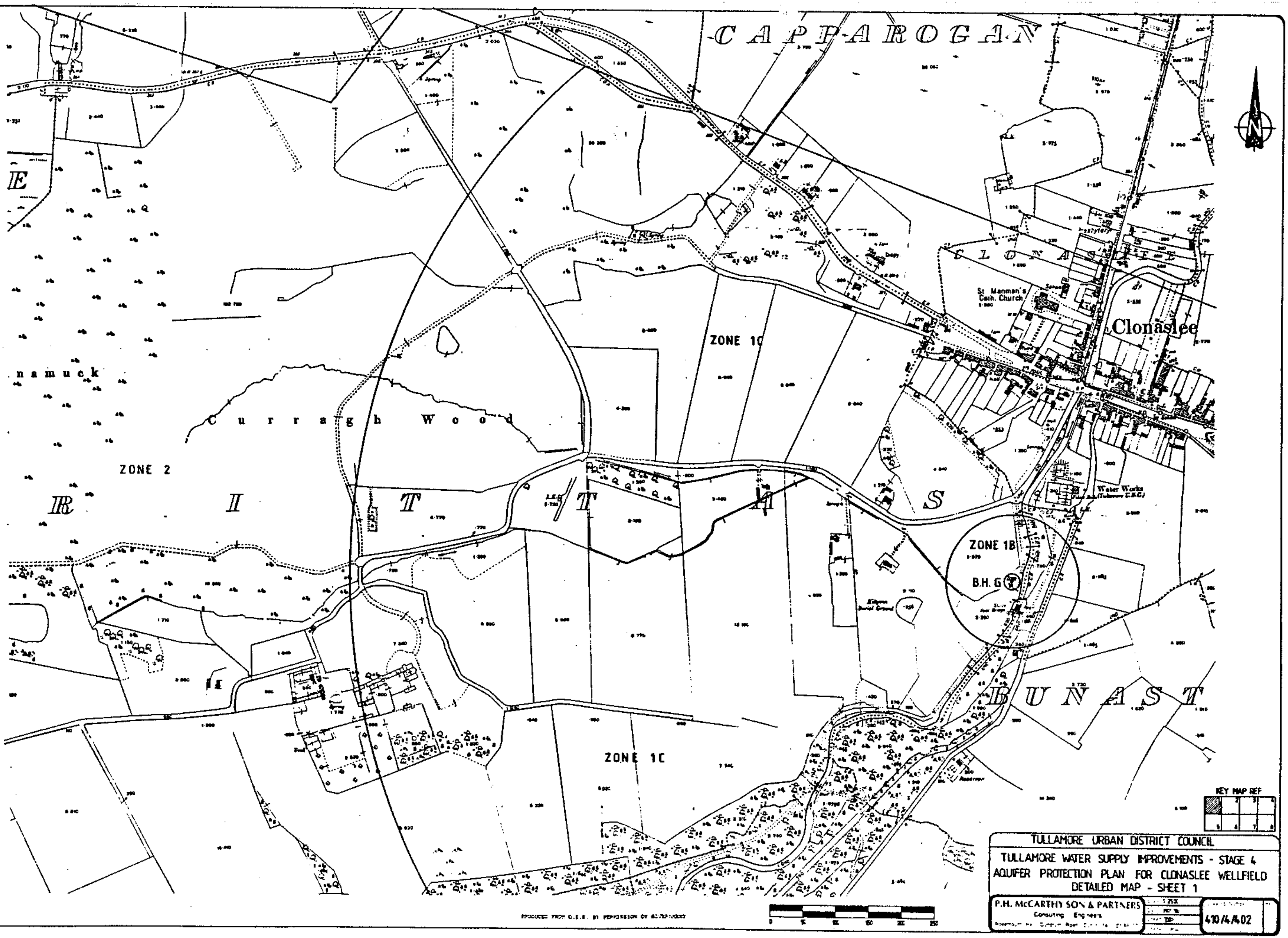
TULLAMORE WATER SUPPLY IMPROVEMENTS- STAGE 4
AQUIFER PROTECTION PLAN FOR CLONASLEE WELLFIELD
KEY MAP

P.H. McCARTHY SON & PARTNERS
Consulting Engineers
Rosemount Hall Dundrum Road Dublin 14 01-988377

Scale	1:10,560
Date	MAY '96
Drawn	DPP
Checked	P.K

Drawing Number: 410/4/401

Fig



CAPPAROGAN
CLONASLEE
Clonaslee
St Manman's Cath. Church
Curragh Wood
ZONE 1C
ZONE 2
ZONE 1B
B.H. G
ZONE 1C
Water Works
Kilgena Burial Ground
BUNAST
KEY MAP REF
TULLAMORE URBAN DISTRICT COUNCIL
TULLAMORE WATER SUPPLY IMPROVEMENTS - STAGE 4
AQUIFER PROTECTION PLAN FOR CLONASLEE WELLFIELD
DETAILED MAP - SHEET 1
P.H. McCARTHY SON & PARTNERS
Consulting Engineers
410/4/402

Fig. 4

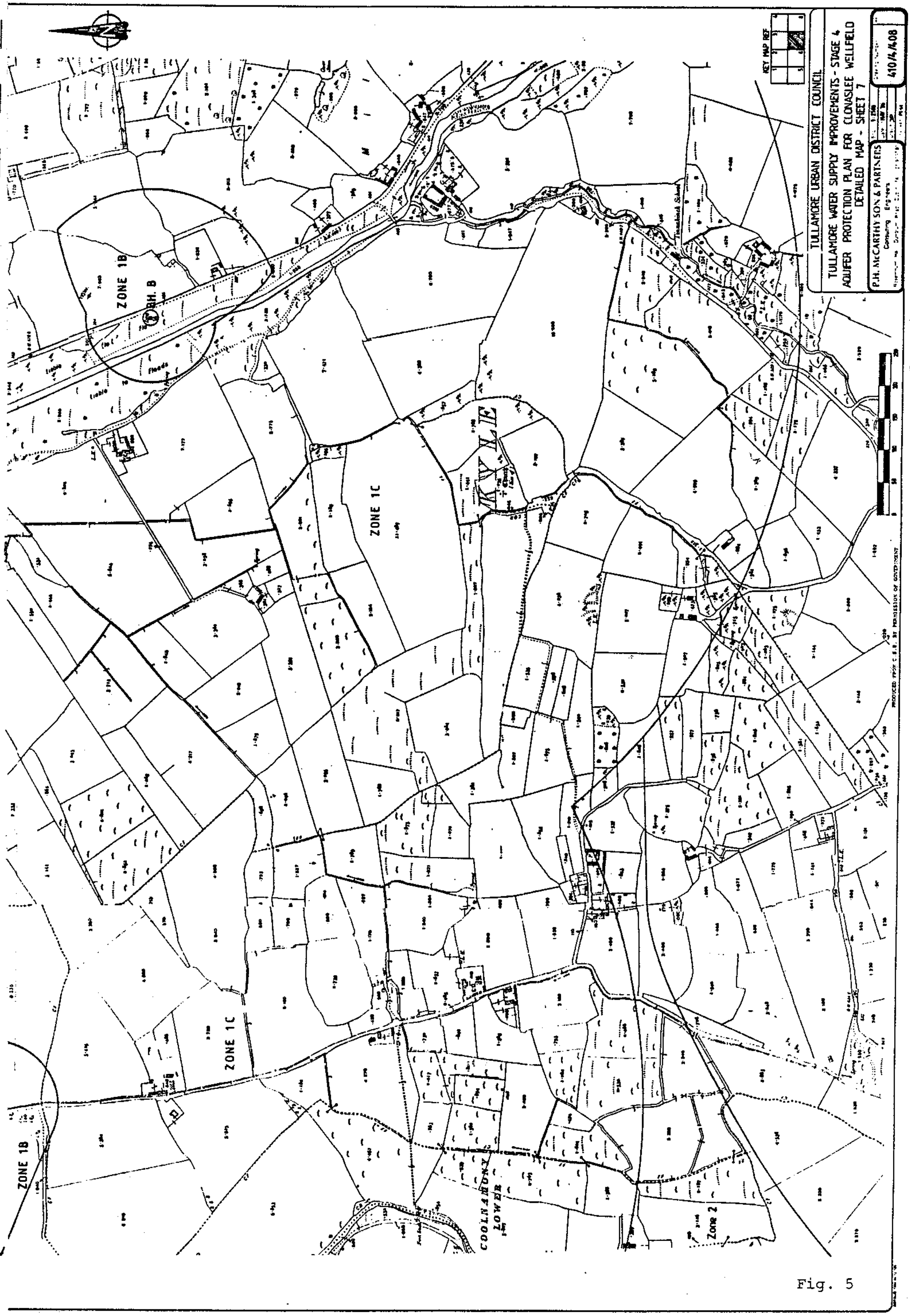

KEY MAP REF
TULLAMORE URBAN DISTRICT COUNCIL
TULLAMORE WATER SUPPLY IMPROVEMENTS - STAGE 4
AQUIFER PROTECTION PLAN FOR CLONASLEE WELLFIELD
DETAILED MAP - SHEET 7
P.H. McCARTHY SON & PARTNERS
Consulting Engineers
410/4/408
ZONE 1B
BH. B
ZONE 1C
ZONE 1C
ZONE 1B
ZONE 2
COOLNAHOWN LOWER

Fig. 5

AQUIFER PROTECTION POLICY

A COUNTY WIDE APPROACH

BY

K.T. CULLEN

International Association of Hydrogeologists (Irish Group)

Seventh Annual Seminar.

Acknowledgments

The Author wishes to thank Wexford County Council for permission to present this paper and the Council's engineering staff for their assistance in assessing the use of groundwater throughout the county.

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I - GROUNDWATER DEVELOPMENT IN COUNTY WEXFORD - AN UPDATE

Wexford County Council has been actively developing groundwater as a major source of potable water since 1978 and this position is likely to continue for the forseeable future. This situation arose with the urgent need to augment existing surface water abstractions which were at, and in some case beyond their design levels. The up-grading of such abstractions with additional surface water would have involved considerable expenditure, which would not arise if a groundwater source was located near to the surface abstraction itself, the rising main or the resevoir site. That so many of these schemes were successfully augmented with groundwater is testimony to the availability of groundwater in Co. Wexford.

The present water supply situation in Co. Wexford is summerised in Table 1 which lists all Local Authority water supply schemes which have a demand of more that 15,000 g.p.d. The schemes have been divided into those that are based on surface water abstractions and those depending on groundwater. It appears that the major water supply schemes in Co. Wexford presently provide some 9.38 m.g.d. of which 6 m.g.d. or 65% is taken from surface waters while the remaining 3.3 m.g.d. or 35% is provided by groundwater abstractions. This situation is likely to change in the near future when major groundwater schemes at Fardystown, Edermine and Adamstown are commissioned, bringing the total water supply to about 12 m.g.d. with groundwater accounting for 50% of this total.

This present situation with regard to major water supply schemes is somewhat misleading as it does not fully describe the full role of groundwater in the supply of fresh water throughout the county. Firstly, in addition to the major schemes listed in Table 1 a further 23 smaller schemes provide groundwater to County Council housing developments. Secondly, it is estimated that around 600 individual Co. Council cottages are supplied by water wells. Thirdly, and more importantly, it is estimated that around 4,000 private water wells are scattered throughout the county providing fresh water for domestic, farming, horticulture and industrial demands. This latter group of abstractions could account for a further 4 - 5 m.g.d. of groundwater based on the water consumption figures for the farm animals recorded by agricultural statistics from Co. Wexford in 1977. Even allowing for a significant level of double counting, the present situation in Co. Wexford is more properly stated as groundwater and surface water supplying equal amounts of potable water. In future years the percentage of the total volume of water derived from groundwater should increase significantly while surface water abstractions should remain fairly static at present levels. This situation will only happen if the present good quality of groundwater is maintained and protected from wide spread contamination and pollution by an effective count y wide aquifer protection policy.

SURFACE WATER ABSTRACTIONS		GROUNDWATER ABSTRACTIONS	
Scheme	Volumes m.g.d.	Scheme	Volume m.g.d.
South Regional W.S.S.	1.20	South Regional W.S.S	2.00
Sow Regional W.S.S.	0.60	Sow Regional W.S.S.	0.10
Enniscorthy W.S.S	0.60	Enniscorthy W.S.S.	0.20
Gorey Regional W.S.S	0.60	Gorey Regional W.S.S	0.50
Ferns Regional W.S.S.	0.09	Coolgreany W.S.S.	0.18
Bunclody W.S.S.	0.10	Camolin W.S.S.	0.015
Wexford Town W.S.S.	1.80	Kilmuckidge W.S.S.	0.12
New Ross W.S.S.	1.00	Bree W.S.S.	0.02
		Ballyhogue W.S.S.	0.015
		Carrickbyrne W.S.S.	0.08
		Clonroche W.S.S.	0.06
Total Abstractions	5.99	Total Abstractions	3.29

NOTE: Proposed groundwater abstractions at Edermine (Sow), Fardystown (South Regional) and Adamstown would bring the total of groundwater abstractions up to the level of surface water abstractions in the very near future.

Table 1. Water Supply Schemes in County Wexford.

II LOCAL GOVERNMENT (WATER POLLUTION ACT, 1977)

This most useful piece of legislation not only deals with the control of discharges to and abstractions from surface waters but also provides a similar control over the development and pollution of groundwater. Also, it provides essentially the same level of protection against pollution to groundwater aquifers as for rivers, lakes etc. The following abstracts from the 1977 Act and the instrument enacted to bring it into force are important. A similar quotation from the Water Supplies Act of 1942 is also of interest.

Section 1

" "Aquifer" means any stratum or combination of strata that stores or transmit s sufficient water to serve as a source of water supply".

" "Waters" includes;

(a) Any (or any part of any) river, stream, lake, canal, reservoir, aquifer, pond, watercourse or other inland waters, whether natural or artificial."

" "Sewage" includes domestic sewage and a combination of domestic sewage and storm water".

" "Trade" includes agriculture, aquaculture, horticulture and any scientific research or experiment".

Section 3

"(1) Subject to subsection (5), a person shall not cause or permit any polluting matter to enter waters."

"(5) Subsection (1) does not apply to:-

(a) discharges of trade effluents or sewage effluents (other than a discharge the subject of regulations under section 4(10), unless where a relevant standard is prescribed under section 26 the discharge complies with that standard)".

Section 4

"(1) (a) Subject to subsection (2), a person shall not, after such a date as may be fixed for the purpose of this subsection by order made by the Minister, discharge or cause or permit the discharge of any trade effluent or sewage effluent to any waters except under and in accordance with a licence under this section".

Section 9

"(1) Each local authority shall cause to be established and kept a register of all licences under section 4 granted by it.

(2) Each local authority shall cause to be established and kept a register of abstractions from waters in its functional area."

Local Government (Water Pollution) Regulations, 1978)

Article 4 First Schedule. Exempted Effluents

Classes of Effluent

"ClassI: Domestic sewage not exceeding in volume 5 cubic metres in any period of 24 hours which is discharged to an aquifer from a septic tank or other disposal unit by means of a percolation area, soakage pit or other method.

Class II: Trade effluent discharged by a sanitary authority in the course of the performance of its powers and duties, other than from a sewer."

Article 37 Third Schedule Exempted Abstractions

"Abstractions which do not exceed 25 cubic metres in any period of 24 hours

Water Supplies Act, 1942

Section 1

"(1) In the Act - the expression "source of water" means any lake, river, stream, well, or spring;".

"Section 20. Where a sanitary authority is enpowered by virtue of this act to take a supply of water from a source of water at any place, such sanitary authority shall have the same rights to prevent interference with the flow of water in, from, or to such source of water and to prevent pollution of the water in such source of water as an owner of land at such place contiguous to such source of water."

In very broad terms the 1977 Act prevents the discharge to aquifers of all effluents except those classed as sewage or trade effluent. These may be permitted under licence issued by the licensing authority which is usually a County Council. The only discharge to an aquifer that is not controlled and is not subject to licence is the disposal of domestic sewage at rates of up to 5 m.3 per 24 hour period.

The 1977 Act defines an aquifer as any stratum that can serve as a source of water supply, which in the context of County Wexford means the vast majority of geological units both within the glacial overburden and the underlying bedrock. In effect then, the Water Pollution Act prohibits the discharge of all effluents to the ground except domestic sewage at rates up to 5 m.3/24 hours. This Act can form the basis of a regional aquifer protection policy with the planning acts providing control over the exempted discharges of domestic sewage.

III GROUNDWATER QUALITY

Groundwater quality in County Wexford is very good at the present time and only a few instances of well pollution have been recorded and these have been caused by either septic tanks or farm yard slurry. However, the present situation does not allow for complacency as unlike river water pollution, any lowering of groundwater quality by point or diffuse sources of pollution would take a considerable time to recover with clean-up programmes involving considerable expense. Furthermore, the time lag between the introduction of a contaminent into the hydrogeological cycle and its appearance in groundwater may deceive the public concerning its real threat for the groundwater quality and the water supply. In most instances a groundwater protection policy will not be able to, nor will it intend to, prevent all contamination. With such a policy the question arises as to how much contamination is tolerable. The answer to this question lies with the specifics of each individual case in terms of the site hydrogeology, the nature of the contamination, the importance of the local supply of groundwater, the quality of the groundwater and many other socio-economic factors.

Point sources of pollution such as septic tanks and farmyards are a greater concern than leaching of inorganic fertilizers. Also, urban areas located on aquifers are a major source of contamination. The following items outline a draft aquifer protection policy that addresses the variable hydrogeological conditions that occur in County Wexford, the lack of available data and the need to provide a flexible policy that can be changed, if and when, new technical information becomes available.

IV - AQUIFER PROTECTION POLICY

The proposed aquifer protection policy attempts to maintain the present good quality of groundwater in County Wexford by preventing effluent discharges to the ground and by locating potential pollution threats away from important aquifers. The policy starts from a point where no level of groundwater pollution is acceptable and moves back from this position to achieve a realistic balance of community interests. By recognising all effluents as the principal cause of groundwater pollution, the policy changes the debate from the value or otherwise of groundwater to the proper control and disposal of domestic, agricultural and industrial liquid wastes.

A system of groundwater protection is suggested that;

(a) recognises the range of hydrogeological regimes present in County Wexford.

(b) the lack of both regional and site specific information.

(c) The need to protect existing groundwater sources.

(d) the need to protect already defined aquifers.

(e) the need to protect as yet undiscovered aquifers.

The desired outcome of preventing groundwater pollution is achieved by defining a high priority zone around all existing abstractions and by protecting all other areas by careful analysis of all proposals for potentially polluting practices by on-site investigation.

IV - 1 SOURCE PROTECTION ZONE

This protection zone is centered on all existing or proposed abstractions and is designed to provide the highest degree of protection to pumping wells. This zone is common to most aquifer protection policies as it recognises the importance of individual abstractions and the ease with which an abstraction can be polluted by short travelled effluents. Most efluents are purified by their passage through the un-saturated zone and by seepage below the water table. Therefore it is the proximity of a particular effluent source that poses the threat rather than the effluent itself. The extent of this high priority area in various countries is given in Table 2. which indicates a range of 10-50 m for this important zone. In some cases the extent of the zone is chosen arbitrarily , in others it is based on the required residence time or delay time required to completely eliminate pathogens in infiltrating effluent i.e. 50 days.

Under the proposed protection policy for County Wexford this inner protection zone would extend to a distance of 30 m. away from the well head in all directions. No effluent generating activities would be permitted under any circumstances within this zone, while normal housing and agricultural activities would be allowed up to 10 m. from the well head itself. This situation does not deviate too much from the historical position adopted by planners and so keeps essentially the same restrictions and prohibitions as previously recommended while affording a high degree of protection to each source. Table 3 summerises the position within the inner protection zone.

PROTECTION AREA	INNER PROTECTION ZONE	
Distance from source (m)	0 - 10 m.	10 m - 30 m
Activities allowed	Water supply activities only	Non-effluent generating activities
Activities not allowed within 30 m. of the groundwater source	Septic tanks, spreading of slurry, manure or sewage sludge, silage clamps, lagoons, chemical stores, foul sewers, sewage of trade effluent treatment plants.	

Table 3. Summary Of Controls Within The Inner Protection Zone.

In any discussion on groundwater protection the fundamental need for sound sanitary completion of groundwater sources to prevent direct ingress of surface drainage at the well head should not be forgotten. This is the most commonest cause of water well pollution and the attached sketches give possible methods of preventing this situation. This feature is perhaps the most obvious pollution risk at Local authority pumping sites in Co. Wexford and is one that needs urgent attention in some cases. The adoption of a standard design for well head completion at all Co. Council wells should be implemented together with a standard for domestic wells for use in planning applications similar to the use of the I.I.R.S. S.R.C. : 1975

IV - 2 AQUIFER PROTECTION ZONE

This area extends from the boundary of the inner protection zone and covers all the remaining parts of the county. The obviously wide extent of this protection zone reflects the varying hydrogeological conditions occurring in County Wexford, the value of all the underlying strata as aquifers of different potential and the need to implement a consistent and realistically achievable groundwater protection policy. Within this zone the only effluent that would be permitted to be discharged to the ground is domestic sewage in the volumes exempted under the Local Government (Water Pollution) Regulations, 1978. No other effluents would be allowed to discharge to the ground without a full investigation of the effect of such effluents on local groundwater and surface water quality. All other potentially polluting practises such as chemical stores, silage pits, lagoons etc. would have to be evaluated to determine the likely impact of such structures on local groundwater and surface water quality in the event of accidents. In this respect the value and vulnerability of groundwater aquifers would have to be assessed within the immediate area of such developments.

V POLLUTION THREAT ASSESSMENT

The adoption of the groundwater protection policy outlined in the last item will involve the County Council in numerous cases of pollution threat assessment. While a blanket policy of protection zones based on distances from pumping wells would have many administrative advantages, such a system would have little scientific basis, contain many inconsistencies and would meet with little public support. The proposed policy, while it will undoubtedly add to the responsibilities of engineers and planners alike will provide a proper assessment of each individual case and provide decisions based on site related investigations.

Risk assessment would involve an understanding of the following:

(i) the nature of the pollutant

(ii) the importance of the aquifer

(iii) the nature of the aquifer (water table or confined)

(iv) the nature and thickness of the overburden

(v) the depth to the water table

(vi) the direction of groundwater movement.

By combining this information it would be possible to estimate the rate of pollutant travel and the effect of this pollution on local groundwater quality. The data gathered from such studies would eventually provide detailed regional vulnerability maps which would assist in the planning process.

V - 1 SEPTIC TANKS

As already mentioned, the main threat to large scale groundwater pollution in Ireland to-day is from point sources of pollution. Septic tanks for the disposal of domestic effluent pose perhaps the greatest single threat. These discharges are not controlled by the Water Pollution Act, 1977 and will continue to represent a major influence on groundwater quality for many years to come.

The available information suggests that properly constructed septic tanks with associated percolation areas can effectively clean domestic effluent with the elimination of most microbes occurring over a short distance from the infiltration zone. However, the effectiveness of this disposal system is controlled by the underlying ground conditions which, in areas of thin overburden will provide little attenuation of the effluent before it reaches the underlying fissured bedrock. In this situation, the required infiltration rates can be easily achieved but the normal purification of the effluent will not take place and the risk of groundwater pollution increases significantly.

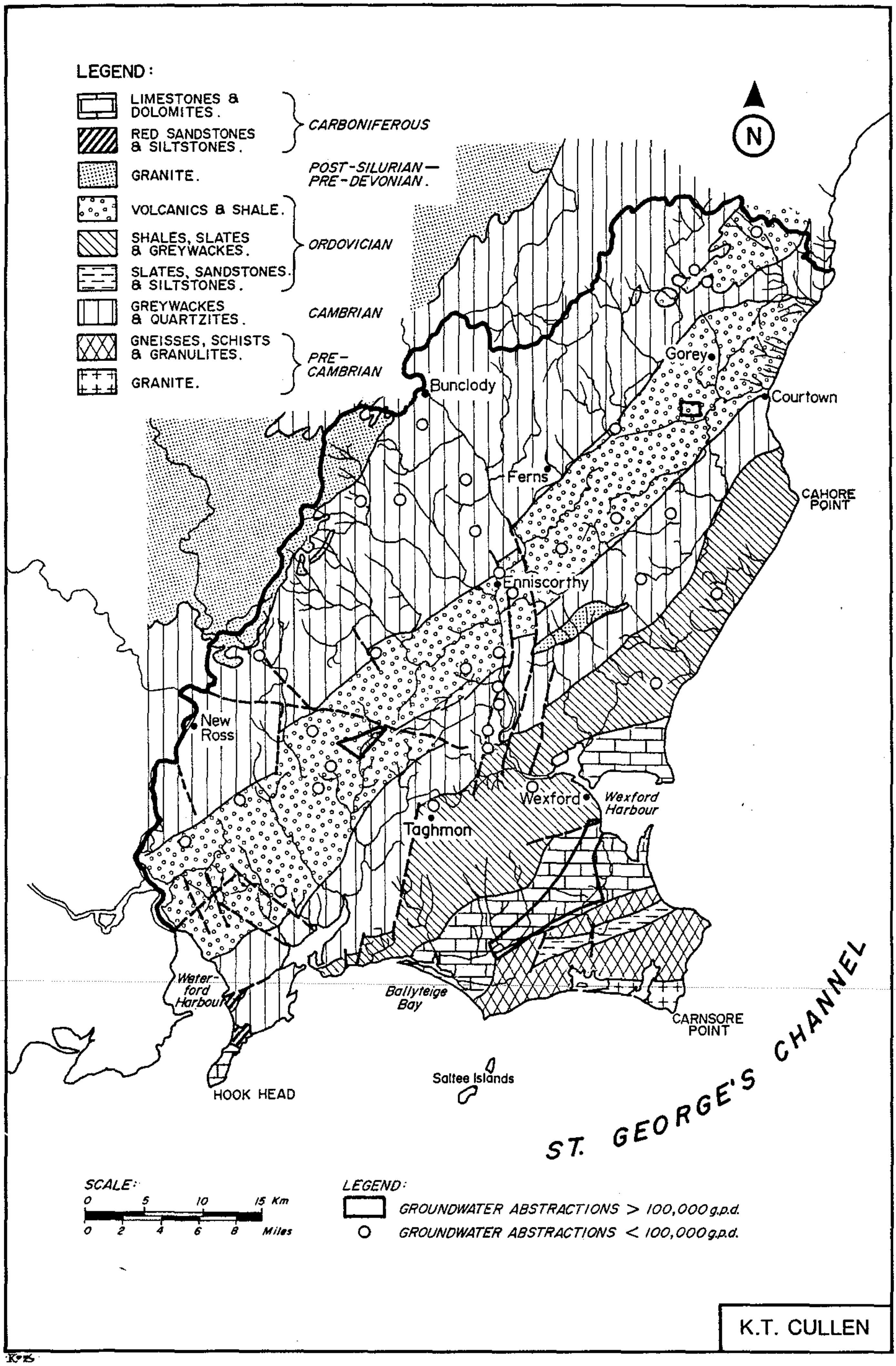
The proposed aquifer protection policy identifies septic tanks as potential pollution risks and while it does not restrict their use it does stress the need for much greater control on the design, location and operation of such disposal units. Therefore, while the assessment of pollution risk attached to a particular septic tank may not be considered of major concern it must be stressed that a large number of poorly designed and mis-placed septic tanks do constitute a significant threat to groundwater quality. However, it should be also noted that various design options are available for the percolation areas attached to septic tanks and where the ground conditions prevent the use of the standard I.I.R.S. design other alternatives could be contemplated. Such situations can only be fully understood where the ground conditions have been studied by the excavation of trial pits and the pollution risk assessed. The difficulty attached to quantifying the pollution risk without adequate on-site investigations is well documented in the I.I.R.S. publication on the design of septic tanks and quoted here for completeness.

* Recommendations For Septic Tank Drainage Systems

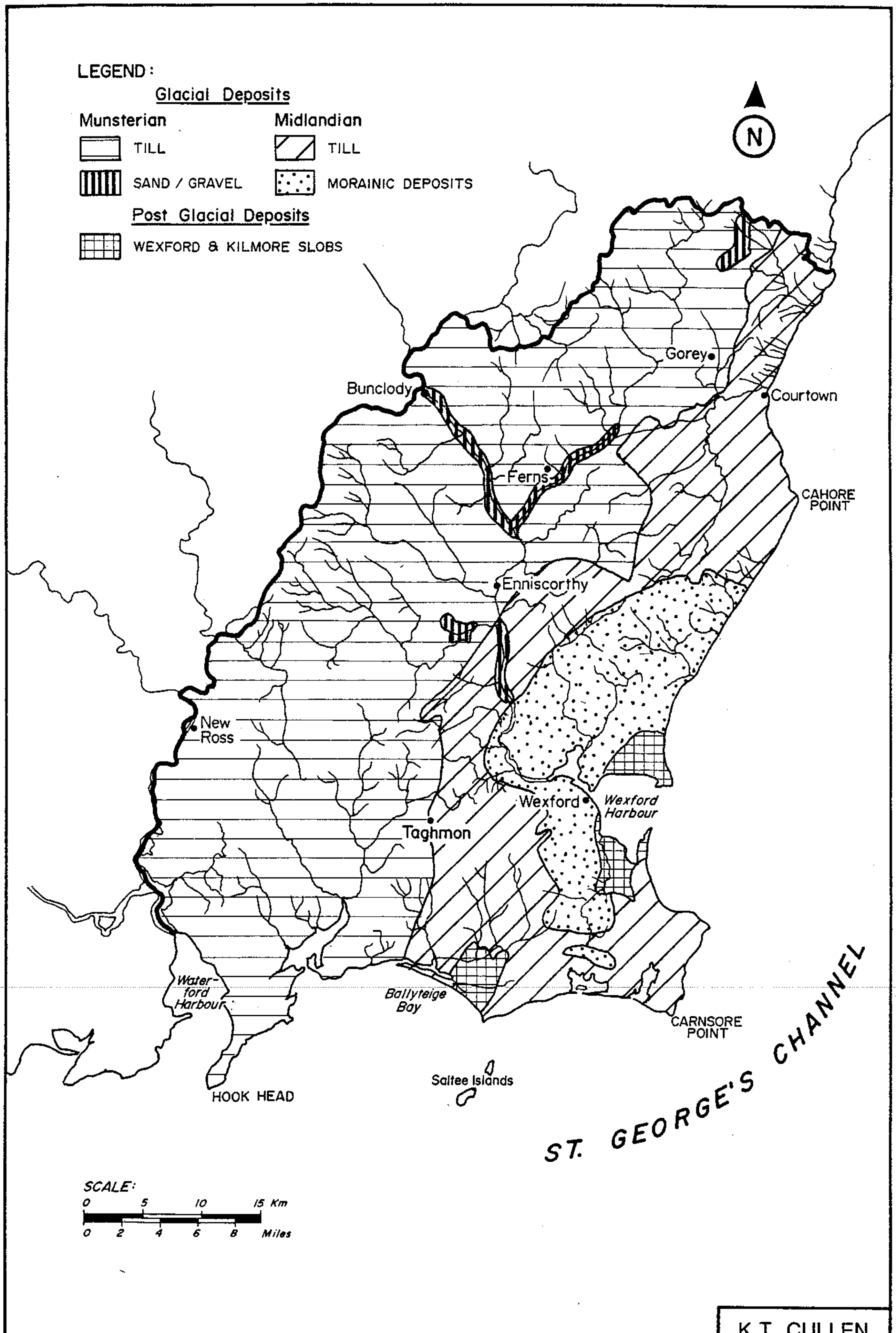
* Suitable For Single Houses I.I.R.S. S.R. 6: 1975.

3.4 Design anbnd Location of percolation areas where no mains water supply is available.

3.4.1 General: In this situation the water supply will normally be obtained from a local source such as a well, spring, or borehole. The isolation of the water supply source from the percolation area is of primary importance since contamination from the percolation area can be carried for considerable distances particularly in sandy soils, gravels and fissured rock. It is not possible to specify with confidence a safe minimum distance between the water source and the percolation area without a detailed knowledge of the geology and soil characteristics of the area and specialist advice should be sought.



LEGEND:
LIMESTONES & DOLOMITES.
RED SANDSTONES & SILTSTONES.
CARBONIFEROUS
GRANITE.
POST-SILURIAN — PRE-DEVONIAN.
VOLCANICS & SHALE.
SHALES, SLATES & GREYWACKES.
ORDOVICIAN
SLATES, SANDSTONES. & SILTSTONES.
GREYWACKES & QUARTZITES.
CAMBRIAN
GNEISSES, SCHISTS & GRANULITES.
GRANITE.
PRE-CAMBRIAN
N
Bunclody
Gorey
Courtown
Ferns
CAHORE POINT
Enniscorthy
New Ross
Wexford
Wexford Harbour
Taghmon
Waterford Harbour
Ballyteige Bay
CARNSORE POINT
Saltee Islands
HOOK HEAD
ST. GEORGE'S CHANNEL
SCALE:
0 5 10 15 Km
0 2 4 6 8 Miles
LEGEND:
GROUNDWATER ABSTRACTIONS > 100,000 g.p.d.
GROUNDWATER ABSTRACTIONS < 100,000 g.p.d.
K.T. CULLEN


LEGEND:
Glacial Deposits
Munsterian
TILL
SAND / GRAVEL
Midlandian
TILL
MORAINIC DEPOSITS
Post Glacial Deposits
WEXFORD & KILMORE SLOBS
N
Gorey
Courtown
Bunclody
Ferns
CAHORE POINT
Enniscorthy
New Ross
Wexford
Wexford Harbour
Taghmon
Waterford Harbour
Ballyteige Bay
CARNSORE POINT
ST. GEORGE'S CHANNEL
Saltee Islands
HOOK HEAD
SCALE:
0 5 10 15 Km
0 2 4 6 8 Miles

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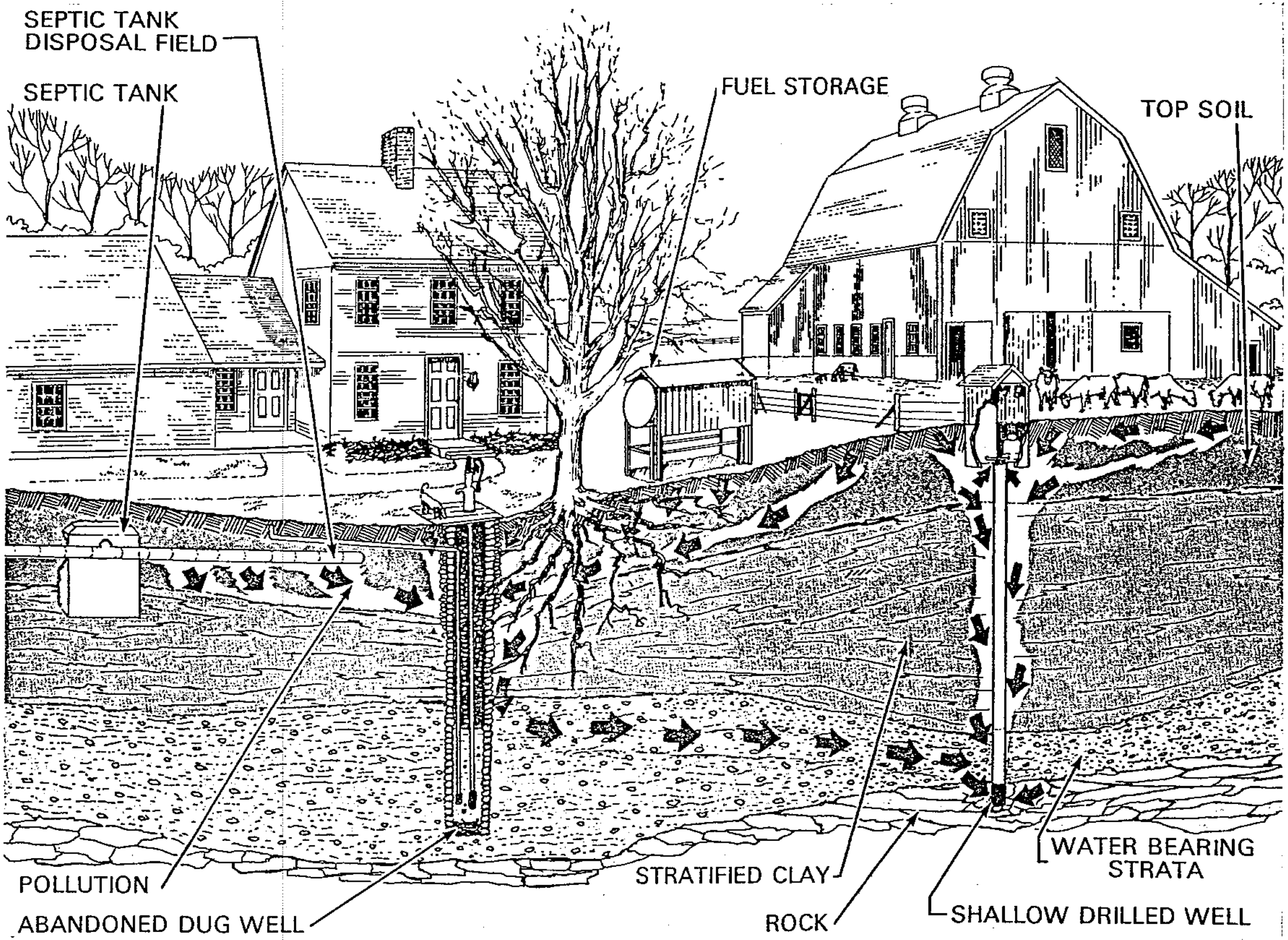
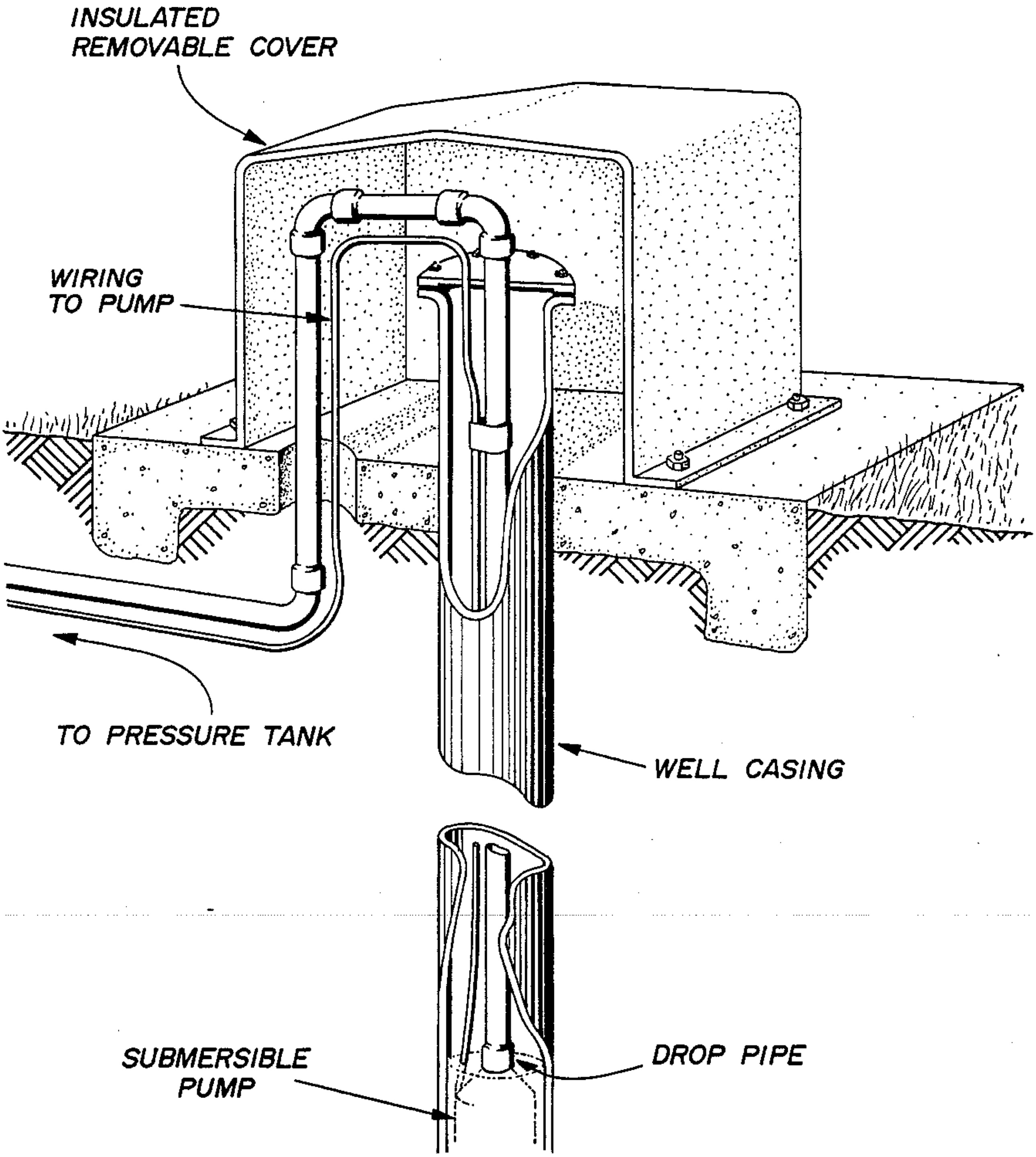


SHALLOW WELLS CAN BECOME POLLUTED MORE READILY THAN DEEP WELLS. NOTE THAT POLLUTION CAN COME FROM UNDERGROUND SOURCES AS WELL AS FROM SURFACE SOURCES.


INSULATED
REMOVABLE COVER
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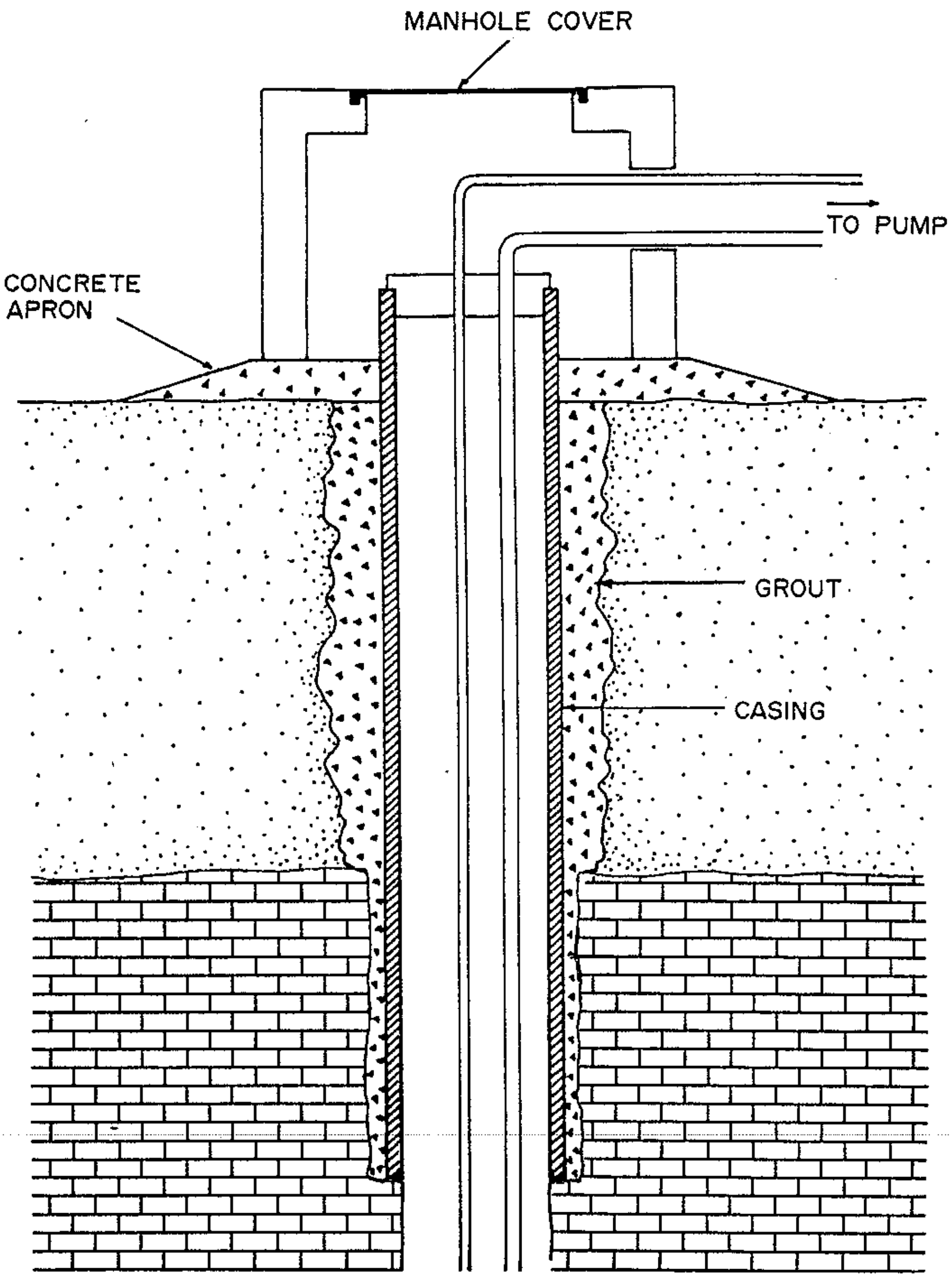
TO PRESSURE TANK
WELL CASING
SUBMERSIBLE
PUMP
DROP PIPE

K08



SEALING A WELL AGAINST POLLUTION.

SEPTIC TANKS AND GROUNDWATER

Donal Daly
Groundwater Section
Geological Survey of Ireland

Disc A10

SEPTIC TANKS AND GROUNDWATER

Donal Daly
Groundwater Section
Geological Survey of Ireland

1. INTRODUCTION

Septic tanks are numerous and widespread in rural Ireland. About 1 million people are not served by public sewerage systems (Gledhill, 1979) and the majority of these use septic tanks.

Septic tank effluent is considered to be one of the principal sources of groundwater contamination in Ireland (Daly & Daly, 1984). Contamination of wells, nutrient enrichment of small streams, ponding of effluent in the vicinity of soakage areas and the associated health hazards have been caused by the siting of septic tank systems on land which is not suitable and by inadequate design and construction of the systems.

In the United States it has been estimated that only 32% of the total land area has the geological and hydrogeological conditions which are required for the safe disposal of septic tank effluent ((USEPA, 1980). In the absence of any known comparable studies in Ireland, it is estimated, based on experience and knowledge of the Irish situation, that over 40% and probably over 50% of the land area here does not have 'good' conditions for septic tanks. However, this does not mean that septic tanks could not be located satisfactorily in the 'poor' areas. With careful consideration and investigation of a site and the installation of an appropriately designed and constructed septic tank system, most sites can be engineered so that environmental effects are minimised.

Septic tanks provide engineers planners and environmental health officers with problems because:

(i) they are numerous and many applications for planning permission for septic tanks are received. Adequate consideration of each application and enforcement of the regulations are time consuming.

(ii) individually they are small sources of pollution and it is usually not feasible to ask for relatively costly site investigations as would be necessary with large sources such as tip sites;

(iii) information on soil, geology and groundwater is usually poor for most areas or is not readily available in sanitary services, planning and Health Board offices. Consequently it is often difficult to take these aspects into account.

(iv) Both septic tank systems and wells are necessary in the absence of public sewerage or water supply systems, yet they are often incompatible on a small site.

However, in view of the problems that are becoming apparent, it is now time for engineers and planners to review the situation and adopt a more critical approach to septic tank location. In particular it is necessary to obtain and use geological and hydrogeological information.

The purposes of this paper are to draw attention to the serious pollution septic tank effluent can cause to groundwater and to offer planners, sanitary services engineers and environmental health officers an approach which takes into account the geology and hydrogeology of the septic tank site. The paper includes:-

1. An outline description of septic tank systems;
2. A summary of groundwater contamination from septic tank systems;
3. A discussion of the factors, particularly the geological and hydrogeological factors, that affect the safe disposal of septic tank effluent;
4. A suggested procedure for considering planning applications for septic tanks;
5. A list of recommendations for the future.

2. SEPTIC TANK SYSTEMS

A septic tank is a buried, watertight container designed and constructed to (1) receive waste water from a building, (2) separate solids from liquids, (3) provide limited digestion of organic matter, (4) store solids and (5) allow the effluent to discharge for disposal in a soil absorption system. The effluent is highly polluting if it directly enters water because it contains bacteria and viruses, nitrogen (40-80mg/l, mostly as ammonia) and phosphorus (10-30mg/l), while the B.O.D. ranges from 20-450mg/l (Bouwer, 1978). Estimates of the number of faecal coliforms in the effluent vary from 0.2 million /100ml to 2.8 million /100ml (Fetter, 1980).

There is a popular misconception that a septic tank itself adequately treats domestic sewage. This is, of course, incorrect. The main treatment of the sewage effluent occurs only after it has left the tank and been discharged into the ground. It is the soil which is relied upon to treat the effluent and render it harmless. Future research on septic tanks should therefore concentrate on this aspect of the system.

The factors which determine the effectiveness of the effluent treatment in the ground are:

1. The type and permeability of the soil and rock;
2. The depth of the water table;
3. The thickness of the overburden (soil and subsoil above bedrock) beneath the percolation area.

As the effluent moves through the granular material of the overburden, various physical, chemical and biological processes take place. Filtration is most important, removing most particulate matter and pathogenic organisms like bacteria and viruses. Chemical and biological reactions also remove many of the organic chemicals and break them down to simpler, usually less harmful, substances. All these processes are encouraged if the overburden is unsaturated and has a low, but significant, permeability.

Two types of problem arise with septic tank systems which are due to the geology of the site - insufficient soakage, which causes the effluent to pond at the surface, and excessive soakage, which allows effluent to move rapidly away and pollute a nearby well (usually on the same property). These two problems are usually mutually exclusive - if there is inadequate soakage due to a low permeability soil and overburden the effluent cannot percolate downwards to contaminate the groundwater. Insufficient soakage causes problems of surface water contamination, odour nuisance amd possibly public health risks. Most people are aware of the problems caused by insufficient soakage but few appreciate the problems caused by excessive soakage where the effluent moves rapidly through the ground into groundwater with minimal purification thus polluting it and perhaps nearby wells. Consequently the main groundwater problems occur in areas of <u>freely draining</u> soils, where there is no surface evidence of pollution. This paper deals mainly with this aspect.

Occasionally pollution of wells can occur in areas with low permeability soils (Deacon, 1986):

1) Breaking through an impermeable layer, e.g. iron pan, during construction of a soakage pit can allow the effluent to move rapidly in an underlying permeable deposit to the well.
2) Deepening of streams contaminated by septic tank effluent can break through the impermeable layers and allow the contaminated water to enter permeable strata.
3) Polluted surface water can run down the outside of the well casing unless the well is sealed by cement grout or bentonite.

3. GROUNDWATER CONTAMINATION BY SEPTIC TANKS

Many wells and springs in Ireland are contaminated due to the presence of small pockets of polluted groundwater beneath point sources such as septic tanks and farmyards. Septic tanks are considered to be one of the principal sources of groundwater contamination.

3.1 Evidence of Contamination

In one local authority area a desk study by the Geological Survey showed that out of a total of 146 groundwater sources, samples from 84 (58%) contained E. coli at the end of the three-day pumping test and/or during the usage of the source. Out of 39 high-yielding wells and springs in the same county, most of which were used for public or group scheme supplies, 29 (74%) were contaminated by E.coli and/or ammonia.

In another county a survey by the local authority Environment Section showed that out of a total of 41 group schemes, 22 contained E.coli when sampled.

Thorn et. al (1986) have examined the groundwater quality in south Co. Sligo and have found that out of 42 sources examined microbiologically 28 (67%) were contaminated either by faecal coliform or faecal streptococci or both. Septic tanks and to a lesser degree farmyard wastes, were shown to be the sources of contamination.

Bassil (1986) has pointed out the presence of high nitrate in groundwater due to septic tanks in an area in north County Dublin.

There are several examples of pollution of domestic wells by septic tanks on Geological Survey files.

As E. coli is a faecal coliform bacteria present in the gut of warm-blooded animals, its presence in groundwater usually indicates either a septic tank <u>or</u> farmyard origin. Consequently it cannot be proved conclusively that septic tank effluent is the main source of contamination in the local authority situations outlined above, although the contrary cannot be proved either. It is argued that septic tank effluent is likely to be a significant cause of contamination for the following reasons:

i) In areas where we have some evidence, septic tanks have been shown to cause contamination.

ii) Septic tanks are more numerous than farmyards.

iii) Contaminated wells are more often located closer to septic tanks than to farmyards.

iv) Because of the usage of soakage pits, septic tank effluent is introduced into the ground below the soil zone (often 2m b.g.l.), reducing the depth of overburden above the water table or fissured rock. In contrast the dirty water and effluent from farmyards is usually at the surface and has to migrate through the soil zone and the full depth of overburden. Consequently, septic tank effluent can often enter groundwater more readily than farmyard effluent.

In the U.S. septic tanks rank highest in the total volume of waste water discharged directly into groundwater and are the most frequently reported source of groundwater contamination (Hagedorn, 1984). According to Patterson et. al. (1971) in a review article on septic tanks in the U.S., "estimates of the number of septic tanks performing adequately range up to 50% of those in use today. These malfunctional systems constitute a severe public health hazard and a major source of contamination of the environment". The article states that "many public health workers feel that the most critical environmental effect of septic tank systems is contamination of private wells. In addition, nutrients released from septic systems which drain into surface waters contribute a significant quantity of fertilizer material to these waters, and can promote their rapid eutrophication. The total evidence available, circumstantial and otherwise, indicates that septic systems exert a significant detrimental effect upon environmental quality". These statements may hold true for Ireland also.

3.2 Septic Tank Contaminants

Contamination by septic tank effluent is usually shown by high concentrations of ammonia, nitrate, chloride and total dissolved solids and the presence of E. coli. If the soil absorption system adequately treats the effluent, pollution is minimised although there could be some, though not usually significant, increase in nitrate and chloride levels.

The most important contaminant from septic tank effluent recorded in normal water analyses is E. coli. This is a faecal coliform bacteria present in the gut of warm-blooded animals. It is an indicator of the possible presence of pathogenic microbes which could cause diarrhoea, hepatitis, dysentry, typhoid fever and gastroenteritis. According to Craun (1979), microbial contamination of groundwater is responsible for large outbreaks of waterborne diseases, particularly gastroenteritis.

The published data on elimination of bacteria and viruses in groundwater has been compiled by Pekdeger and Matthess (1983), who show that in different investigations 99.9% elimination of E. coli occurred after 10-50 days. The mean of the evaluated investigations was 25 days. They show that 99.9% elimination of various viruses occurred after 16-140 days, with a mean of 35 days for Polio-, Hepatitis- and Enteroviruses.

3.3 Where do Groundwater Contamination Problems Occur?

Problems of groundwater contamination occur generally where:

i) the overburden consists of highly permeable sand and gravel;

ii) karstic or fissured rocks are present close to the ground surface e.g. parts of Galway, Roscommon, Clare but also areas in every county.

iii) the water table is close to the bottom of the soakage pit or percolation area so that the unsaturated zone is insufficient to treat the effluent adequately.

3.4 Why are Septic Tanks Major Sources of Contamination?

Septic tanks are collectively major sources of groundwater contamination for the following reasons:

i) They discharge a high volume of wastewater into groundwater.

ii) Many septic tanks are sited too close to wells;

iii) Many septic tanks are located in areas where the overburden is thin and underlain by karstic limestones so that the effluent gets directly into groundwater;

iv) Soakage pits are used too often rather than percolation areas. A soakage pit, although easy to construct, is usually an inadequate means of disposing of effluent because it releases the effluent over a small area which may become clogged or lose the ability to treat the effluent. Also they are deep and so reduce the depth of overburden above the water table or above fissured rocks; (see Figure 1).

v) In many local authority areas, the planning requirement for percolation areas is not enforced.

vi) Septic tanks are seldom maintained and are usually not emptied regularly.

However there are solutions to these problems which are considered below.

4. REMEDIES

4.1 The Septic Tank

The septic tank should be emptied regularly - preferably once a year(IIRS, 1975). Many householders do not do this at present. Consequently, local authorities should consider providing a septic tank desludging service.

4.2 Soakage Pits and Percolation Areas

Soakage pits should not be allowed for any new installation. Instead pipe distribution systems should be installed because they disperse the effluent over a relatively large area, close to the ground surface, and therefore as far as possible above the bedrock and water table (see Figure 2).

Proper site suitability testing as recommended by IIRS (1975) should be carried out although it should be remembered that groundwater contamination is usually the result of excessive soakage. Even where soakage is excessive, a properly designed and constructed percolation area can retard percolation and consequently is beneficial here also.

Sufficient land should be available for a reserve percolation area (Deacon, 1986) so that if problems arise a second pipe distribution system can be constructed. Resting of the percolation system allows the soil to drain and re-aerate, thus encouraging degradation of the clogging mat which may build up at the infiltrative surface (Canter and Knox, 1985). The process of alternate dosing and resting of the percolation area can markedly prolong the effective life of the system.

O'Brien (1981) and Deacon (1986) suggest that the gravel surrounding the percolation pipes should be covered with a pervious material - hay, straw, pine needles, paper - to exclude backfill from entering the gravel rather than an impervious plastic sheet as recommended by IIRS (1975). This improves the maintenance of aerobic conditions and increases evapotranspiration.

According to Canter and Knox (1985), trench systems are better than bed systems because they provide more sidewall area and consequently better drainage of the effluent.

4.3 Overburden and Unsaturated Zone

The overburden acts as a filtering medium which can filter out pathogenic bacteria and viruses, and also can attenuate the chemical pollutants by reactions such as precipitation, ion exchange and adsorption.

The type of overburden is important because this dictates the amount of soakage and the risk of pollution. Clayey till* has a low permeability and consequently soakage is usually poor and might not be adequate. In this

* Till consists of a variable assortment of rock debris which ranges in size from fine rock flour (clay size) to boulders. It is often called boulder clay.

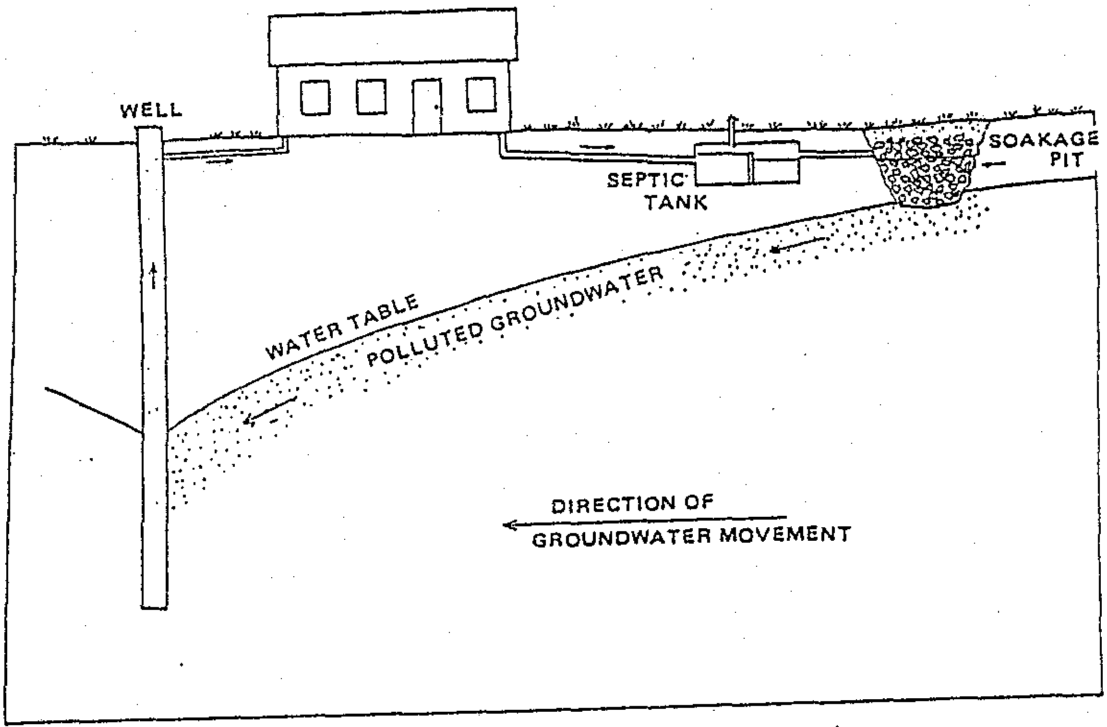


Figure 1. Pollution of groundwater by disposal of septic tank effluent in a soakage pit.

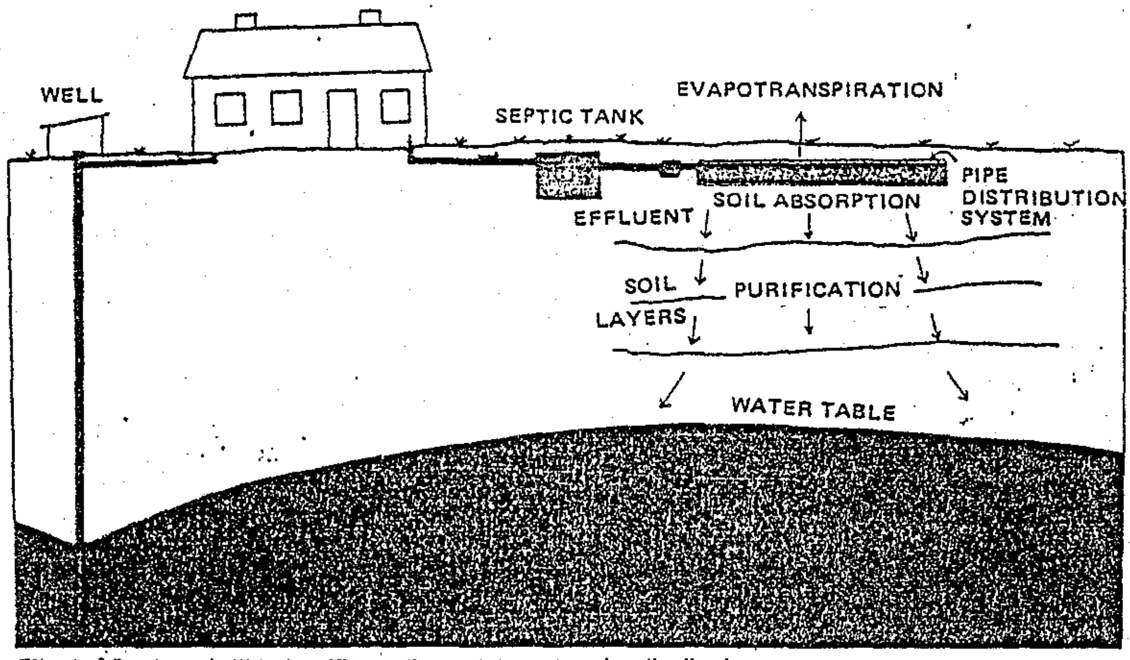


Figure 2. Septic tank with the effluent disposed through a pipe distribution system.

(Copied from Daly, 1985).

situation the effluent either ponds at the surface or the septic system ceases to operate. Sandy till usually has adequate soakage without any risk of pollution. Sand and gravel have excellent but sometimes excessive soakage.

The IIRS recommend that a percolation test should be carried out on the septic tank site (IIRS, 1975). Estimated percolation rates (or values of "T" as described by IIRS (1975)) for various overburden or soil types are given below:

Overburden type	Percolation Rate or Value of "T"	
	min/in	min/cm
Gravel, coarse sand	<1	(<0.4)
Coarse to medium sand	1-5	(0.4-2.0)
Fine sand, clayey sand	6-15	(2.4-6.0)
Sandy clay, sandy till	16-30	(6.3-12.0)
Clayey till	31-60	(12.2-23.6)
Silty clay, clay	61-120	(24.0-47.2)

(adapted from USEPA (1980)).

If the percolation rate is greater than 60min/in (24min/cm), the site is not suitable for a septic tank (IIRS 1975) as the soakage is inadequate. It has been suggested that where the percolation rate is excessive - less than 1min/in (0.4min/cm) - the soil in the percolation area should be replaced by a suitably thick (0.6m) layer of sandy clay or sand (USEPA, 1980). However, percolation test results should be examined critically because results tend to vary and depend particularly on the procedure used and the soil moisture conditions at the time of the test (USEPA, 1980).

If effluent enters directly into fissured rocks, chemical attenuation is poor and there is minimal filtration of pathogenic microbes. There should be at least 1.0m of soil or fine granular material between the pipe distribution system and fissured rocks.

An unsaturated zone considerably increases the attenuating capacity of granular material. Keenan (1985) has suggested that the minimum distance between the pipes and the highest water level should be 0.5m. However, a greater thickness of unsaturated zone would be preferable, and a minimum of 1.0m is recommended.

One way of providing a layer of unsaturated granular material (and the only way in some areas) is to construct a mound above ground level with the pipe distribution system set in a sand bed within the mound.

4.4 Geology, Depth to Bedrock and Aquifer Protection Maps

At present most planners do not have sufficient geological or hydrogeological information readily available to allow them to take groundwater into account when considering planning applications for septic tanks. In several European and North American countries the planning authorities are obliged to consult hydrogeologists in the water supply authorities. However, in Ireland hydrogeologists are not employed by the local authorities. An alternative is for each planning office to have geology maps, soil maps, depth to bedrock maps, aquifer maps and aquifer protection maps which can be examined by planners when considering planning applications.

As described in the previous section the type and thickness of overburden are crucial factors in considering the location of septic tanks, consequently maps of overburden would be useful to planners. Overburden (or Quaternary) maps are available for Counties Limerick, Dublin, Offaly and Galway, although the scale of these maps is small - 1:63,360 or 1:126,720 - and the Limerick, Offaly and Dublin maps are reconnaissance maps whereas the Galway map was compiled from poor data. Good quality information on 1:10,560 scale maps is present in the Geological Survey for counties Kerry and Wicklow and parts of counties Kildare, Carlow, Limerick, Sligo, Leitrim, Monaghan, Louth and Cork. Overall, information on the overburden geology is poor and when available it is not published. However if planners create a demand for this type of information more emphasis might be given to Quaternary geology within the Geological Survey and the third level colleges of education.

Soil maps, which are available for certain counties from An Foras Talúntais, provide useful information on the overburden and on the drainage characteristics of the soils, although the scale of the maps is fairly small - 1:126,720.

Depth to bedrock maps are either completed or are in the process of being completed for the following counties : Galway, Dublin, Laois, Kilkenny, North Mayo, Wicklow and Kildare. However only the Galway map is readily available at present. The other maps can be examined in the Geological Survey. If planners are interested in a particular area, they can contact the Geological Survey requesting details on the type and thickness of overburden and on the bedrock geology.

It is emphasised that the accuracy and reliability of the overburden and depth to bedrock maps are very dependent on the detail of the mapping and on the density of the data available. Depth to bedrock data can be very variable over the area of a county. Therefore these maps cannot be used as the sole basis for allowing or rejecting a planning application - the site in question could be 1km or more from the nearest data point. However, these maps can be used as a guide and as a reason for putting the onus on an applicant to show that the site is suitable by carrying out an investigation e.g. by digging deep holes on the site.

An aquifer protection scheme has been proposed by the Geological Survey to enable planners and engineers to take account of groundwater when considering developments, such as septic tanks, which have the potential to pollute (Daly and Wright, 1981) (Daly, 1986). The scheme involves the production of a map which divides an area such as a local authority area into aquifer protection zones according to the degree of protection required, Zone 1 requiring the highest degree of protection and Zone 4 the least. Zone 1 is a source protection zone around each designated groundwater supply source (public and group scheme supplies and important industrial supplies). It is sub-divided into 3 sub-zones; 1A, 1B and 1C. Zone 1A is the area within a 10m radius from the source, Zone 1B is the area between radii 10-300m and Zone C is the area between radii 300-1,000m. These distances can be varied depending on the local hydrogeological conditions and should only be considered as a guide. The scheme recommends that septic tanks should not be allowed in Zones 1A and 1B unless the aquifer is overlain by significant thicknesses of low permeability strata.

4.5 Distances between Septic Tanks and Wells

A minimum distance of 30m between a well and septic tank is considered to be "safe" by many regulatory authorities both in Ireland and in other countries.

McGinnis and DeWalle (1983) in a review article on the movement of typhoid organisms, show that bacteria travelled more than 30m in groundwater in 10 out of 26 studies. The bacteria travelled more than 500m in 4 studies in sand, gravel and fissured limestone. Vaughn et al. (1983) quote examples of the movement of viruses to wells 30m, 45m, 183m and 250m from the pollution source. In work carried out on Long Island, New York, they found that viruses had moved 67m to a well from a percolation area serving an apartment block. It is clear that the 30m distance is inadequate in many situations and should be changed.

The safe distance between a well and septic tank depends on a number of interrelated geological and hydrogeological factors:

(i) the type, permeability and thickness of overburden;

(ii) the type and permeability of the bedrock;

(iii) the depth to the water table;

(iv) the hydraulic gradient;

(v) the pumping rate;

(vi) the attenuation of the effluent as it moves towards the well.

If all these factors were known it would be possible to calculate the safe distance. Obviously this is seldom possible.

The aquifer protection policy proposed by the Geological Survey recommends that septic tanks should not normally be located within 300m of public and group scheme wells and springs.

Table 1 gives suggested "safe" distances for the location of septic tanks and wells. These distances are intended only as a guide, and do not guarantee that contamination will not occur if they are adhered to. They are based partly on scientific calculations and partly on experience. However they are considered to be a better guide than the general 30m recommended distance because they are based on the factors which affect the movement of pollutants from septic tanks to wells. The distances in Table 1 can be reduced somewhat when:

(a) the well is deep and the upper part is lined and sealed with cement grout:

(b) the well is located upslope of the septic tank.

4.6 Density of Septic Tanks

In the USA numerous cases of groundwater contamination have been reported in areas of high septic tank density: site sizes in these areas range from less than 0.13ha (1/3 acre) to 1.2ha (3 acres). Yates (1985) has concluded that the single most important means of limiting groundwater contamination by septic tanks in the USA is to restrict the density of these systems in an area. The U.S. Environmental Protection Agency has identified three density ranges:

(1) low (less than $4/km^2$);

(2) intermediate ($4\text{-}16/km^2$); and

(3) high (greater than $16/km^2$) (reported in Yates, 1985). Areas with a septic tank density of greater than $16/km^2$ (1/6.5ha) are designated as regions of potential contamination problems.

TABLE 1

Suggested Safe Distances of a Well from a Septic Tank

Type of Overburden	Depth of Overburden (m)	Minimum Depth to Water Table (m)	Distance from Septic Tank (m)
Clayey till*	1.0 - 2.0	1.0	30+
Clayey till	2.0+	1.0	10-30
Sandy till	1.0 - 2.0	1.0	45+
Sandy till	2.0 - 5.0	1.0	30-45
Sandy till	5.0+	1.0 - 5.0	30+
Sandy till	5.0+	5.0	20-30
Sand and Gravel	1.0 - 2.0	1.0	60+
Sand and Gravel	2.0 - 5.0	1.0	40-60
Sand and Gravel	5.0+	1.0 - 5.0	40+
Sand and Gravel	5.0+	5.0+	30-40

*till = boulder clay

Notes: (i) Depth relates to the percolation pipe or bottom of the soakage pit and not to ground level.

(ii) Where the overburden or the depth to the water table is less than 1.0m, the risk of contamination is high and the percolation should take place through a mound built up above ground level.

Planners in Ireland might consider this approach as a method of controlling the location of septic tanks. How applicable is it to Ireland?

Undoubtedly, the higher the density of septic tanks in an area the greater the potential risk of pollution. In Ireland, groundwater beneath areas with ribbon development are prone to pollution. However the risk depends more on the geology and hydrogeology than on the density.

In an area of thick (6m+) fine grained overburden and deep (6m+) water table, bacteria and viruses are likely to be filtered out of the effluent. Consequently the main pollution problem in this situation is from the chemicals in the effluent - mainly nitrate. However the increase in nitrate levels should not be a significant problem in Ireland except where the housing density is very high - far higher than $16/km^2$ - or unless the nitrate levels are already high from other sources. For instance a density of 60 septic tanks/km^2 (1/1.66ha) would cause an increase of 1mg/l NO_3 as N assuming that the effective recharge is 0.5m/yr, the average nitrogen concentration in the effluent is 30mg/l and there is no denitrification. Such an increase in nitrate is negligible.

In an area of thin or minimal overburden on karstic limestones where the effluent is flowing rapidly into groundwater from soakage pits, a very low density could cause significant groundwater contamination, particularly microbial contamination.

Consequently the concept of using maps showing densities of septic tanks is not useful unless maps of the geology and hydrogeology, and particularly overburden geology, are available and all the information is integrated.

4.7 Pollution Index Technique

Cartwright and Sherman (1974) consider that the volume of effluent and the permeability and thickness of overburden between the level of the percolation pipes and the shallowest aquifer are the most significant factors in evaluating the pollution hazard from septic tanks. They used the standard percolation test as a measure of permeability, the housing density as an approximation of volume of effluent, and a specific measure of the thickness of material between the point of effluent discharge and the underlying aquifer. From these parameters they developed a formula for estimating pollution hazards:

$$Pi = \frac{200\sqrt{D}}{\sqrt{I\ (T-5)}}$$

where Pi = pollution index

D = housing density, the number of residences with septic systems within a distance of 450m (a circle having an area of ¼sq mi (160 acres)).

I = time, in minutes, for water to fall 0.15m (6"), as measured in the standard percolation test as prescribed by the Illinois Department of Public Health.

T = thickness, in feet, of soil between discharge level and the underlying aquifer to be protected. If T is less than 5, assume T-5 = 1 (Berg et al., 1984) (The value was 0 in the original paper).

Values of Pi greater than 10 suggest that some potential for pollution exists and more detailed information on the site should be gathered. If the Pi value is less than 10, the potential for significant pollution of groundwater is probably fairly low.

Cartwright and Sherman (1974) published this approach with a view to providing guidelines to planners who are routinely involved with the regulation of septic tanks. However it was intended not as a final solution but as an approach which should be discussed and evaluated. It would be worthwhile examining this approach to see if it has applications for the Irish situation.

4.8 Assistance from Hydrogeologists

In certain circumstances, for instance if an application is received for permission for a septic tank close to a public or group scheme water supply, planners should consider obtaining assistance and advice from a hydrogeologist. The approach that a hydrogeologist would take is indicated in the example described in Appendix 1.

5. ASSESSING A SEPTIC TANK PROPOSAL - PRACTICAL STEPS FOR PLANNERS

The suggestions below are intended to assist planners and engineers in taking account of groundwater when assessing a proposal for a septic tank system. Admittedly some of the suggestions are not practical in the short term either due to lack of the required information or inadequate staffing levels. However they are a long term goal which must be aimed for. It is recommended that initially areas needing special attention should be identified and in those areas the following step-by-step approach should be adopted.

5.1 Preliminary Assessment - Desk Study

(i) Examine the topography, soil, geology and depth-to-bedrock maps of the area, if available.

(ii) Assess the overburden and bedrock types for degree of permeability, variability and thickness.

(iii) Examine the aquifer and aquifer protection maps and check for the presence of public, group scheme and industrial water supplies.

(iv) Assess the aquifers for type of permeability - intergranular or fissure -, depth to water table, groundwater flow direction, groundwater quality and in particular check if any existing wells are contaminated by point pollution sources.

5.2 Site Visit

(i) Note topography and assess probable groundwater flow direction. (Groundwater flow normally mirrors large-scale topography).

(ii) Examine soil, cuttings into overburden and rock outcrops (if present) on site. A minimum requirement would be to collect and examine a sample of the overburden beneath the percolation area. This could be done by requesting the applicant to dig a trial pit at least 2.0m deep.

(iii) Note the vegetation type as it may indicate wetness or shallow soils.

(iv) Check distance of proposed percolation area from existing and proposed wells.

(v) Enquire about depth to bedrock in area. If the houseowner has already drilled a well the depth to bedrock should be known.

(vi) Check for neighbouring wells and septic tanks.

(vii) Assess the depth to the water table preferably by measuring it in nearby wells. If a stream is present nearby and the overburden and rocks are free draining the water table is likely to be close to the stream level. If the overburden and rocks are poorly draining, the water table is likely to be close to ground surface. Assess if the water table depth given by the applicant is reasonable.

(viii) Ensure that a properly conducted percolation test has been carried and assess the results.

5.3 Conclusions

In the final assessment of the proposal the following aspects of the site should be considered in conjunction with the "remedies" outlined in Section 4 and the criteria in Table 2.

(i) previous experience in the area;
(ii) topography;
(iii) geology, particularly overburden geology;
(iv) importance of groundwater in area;
(v) groundwater flow direction;
(vi) estimated minimum depth to water table;
(vii) permeability or drainage characteristics of overburden and/or bedrock;
(viii) distance of septic tank from existing and proposed wells and springs;
(ix) the aquifer protection zone;
(x) the existing water quality;
(xi) the vulnerability of groundwater in the area.

In the case of a sensitive or important planning application, the Planning Section should consult the Geological Survey or employ a hydrogeological consultant. Advice on the septic tank, the percolation area, septic tank failure and alternatives to septic tanks can be obtained from IIRS.

It can be argued with justification that these proposals would add to the work load of local authorities and Health Boards. However, it is considered that the approach outlined is necessary to make an informed technical decision. In the short term special attention should be given to planning applications for septic tank systems in the following situations:-

(i) where a well and septic tank are located on the same site;
(ii) near (i.e. within 1km) public, group scheme and industrial groundwater sources;
(iii) on karstic limestone aquifers;
(iv) on low permeability soils and overburden;
(v) where bedrock is at or close to ground surface.

Pressure from public representatives on a planning application is sometimes a problem for planners. If the groundwater is at risk, an effective response might be to show how the applicant could end up recycling (i.e. drinking) constituents from their own sewage if permission is granted.

TABLE 2

SITE CRITERIA FOR PERCOLATION AREAS

(adapted from USEPA (1980))

ITEM	CRITERIA
Topography	Level, well drained areas, crests of slopes, convex slopes most desirable. Avoid depressions, bases of slopes and concave slopes unless suitable surface drainage is provided.
Typical horizonal separation distances from wells	See Table 1
Soil/overburden texture	Soils with sandy or loamy textures are best suited. Gravel with a high percolation rate, and slowly permeable clays are less desirable.
Soil structure	Strong granular, blocky or prismatic structures are desirable. Platy or unstructured massive soils should be avoided.
Soil/overburden colour	Bright uniform colours, particularly brown, indicate well-drained, well aerated soils. Dull, grey or mottled colours indicate seasonal or continuous saturation and are unsuitable.
Unsaturated depth	A minimum of 1.0m of unsaturated soil should exist between the bottom of the system and the seasonally high water table or bedrock.
Percolation rate	1-60min/in (average of at least 2 percolation tests). If the percolation rate is less than 1min/in the soil should be replaced with 0.6m sand or clayey sand. If the percolation rate is 60+min/in the soakage is inadequate.
Septic tank density	Particular care should be taken in areas of ribbon development or on housing estates where each site has a well and septic tank.

6. RECOMMENDATIONS

6.1 Public Awareness

(i) Local authority engineers and planners, public representatives, and the general public need to be more aware of groundwater and its importance as a source of water supply.

(ii) We need an increased awareness of the potential of septic tanks to contaminate groundwater.

(iii) Education is needed. A simple pamphlet on septic tanks should be prepared and distributed to public representatives, and community groups; a copy should be given to all applicants who seek permission for a septic tank.

6.2 Septic Tank Systems

(i) In areas where septic tanks are of very doubtful suitability, for instance where the rock is close to the ground surface, alternative methods of sewage disposal should be considered.

(ii) A study of septic tank systems should be initiated which would concentrate on the effluent disposal aspect rather than on the operation of the septic tank itself.

6.3 IIRS Recommendations

(i) The IIRS recommendations (IIRS, 1975) should be adopted by all local authorities (if they have not already done so).

(ii) Percolation tests and trial pits should be obligatory. Where the value of "T" is less than 1.0 (i.e. where soakage is excessive) permission for the septic tank system should not be given unless remedial measures are taken.

(iii) Percolation areas rather than soakage pits should be used to dispose of septic tank effluent.

(iv) The IIRS booklet (IIRS, 1975) should be updated to include a section on groundwater and recommended minimum distances of septic tanks from wells.

6.4 Geological and Hydrogeological Aspects

(i) The minimum distances of wells from septic tanks in various geological situations should be studied further.

(ii) The pollution index technique (see Section 4.7) should be examined to see if it is relevant to the Irish situation

(iii) A pilot study should be undertaken to see if a map could be prepared, based on the soil, geology and hydrogeology, showing areas suitable for septic tanks or alternatively rating the area on its suitability for septic system operation.

(iv) The importance of geology and hydrogeology in locating septic tanks has been shown in this paper. However the Geological Survey cannot at present provide the required information for all areas. Engineers, planners and environmental health officers should request the Geological Survey and the Department of Energy to give a high priority to the production of relevant information and maps.

(v) As there are too few geologists employed in the public service to provide up-to-date geology maps, particularly overburden maps, it is crucial that engineers and planners record geological and hydrogeological data and send them to the Geological Survey. The following information would assist geologists in producing relevant maps and reports:

(a) Overburden: Type - sand, gravel, till (boulder clay), clay, peat. Colour. Depth-to-bedrock.

(b) Bedrock: Colour, grain size, degree of jointing/bedding, texture. Rock type, if known.

(c) Hydrogeology: Details of wells - dug or bored, location, well construction, total depth, depth-to-bedrock, overburden type, rock type, depth to water table, yield, drawdown, water quality.

Details of springs - location, low flow.

Other details - water analyses, swallow holes, caves, etc.

(vi) In the short term local authorities should take as many of the steps outlined in Section 5 as are practicable in those situations and areas where groundwater and surface water are vulnerable to contamination by septic tanks.

6.5 Local Authorities and Health Boards

(i) More emphasis should be placed on enforcement of the planning regulations by local authority planning sections and/or Health Boards.

(ii) The provision of a septic tank desludging service by local authorities should be considered.

(iii) Communications should be improved between the public bodies with expertise on the various aspects of septic tank systems.

7 ACKNOWLEDGEMENTS

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APPENDIX 1

ASSISTANCE FROM HYDROGEOLOGISTS - AN EXAMPLE

A1 INTRODUCTION

The Geological Survey was requested by a local authority to advise on the likely effects a proposed septic tank would have on existing and proposed public supply boreholes. The existing boreholes are 9.0m deep, yield 591m^3/d (130,000gph) from a gravel aquifer and the projected yield for further boreholes is 2273m^3/d (500,000gpd). The proposed septic tank was located 250m from the boreholes.

A2 GEOLOGY

The geology consists of 9.0m gravel overlying limestone. The gravel is in a river valley and extends approx. 150m up the side of the valley in the direction of the septic tank. In the septic tank area the limestone is overlain by 1m free-draining sandy soil.

A3 HYDROGEOLOGY

The gravel is a major aquifer capable of yielding large quantities of water.

The recharge area needed to supply the boreholes can be calculated as follows:

Effective rainfall (rainfall less actual evaporation)	= 450mm
Assume 90% recharge to groundwater	= 405mm
Present yield	= 591m^3/yr
	215715m^3/yr
Area required to yield 215715m^3/yr	= 53.26ha
= a circular area of	412m radius
Future yield	= 829645m^3/yr
Area required to yield 829645m^3/yr = a circular area of	808m radius.

The septic tank falls within these areas.

Analysis of the pumping test data on the boreholes suggests that the permeability of the gravel is in the range 50-100m/d. It is calculated that pumping the existing boreholes at 591m^3/d for 100 days would cause a drawdown of 0.62m and 0.34m at 100m and 250m distances, respectively, from the boreholes assuming that no recharge occurs. This shows that the septic tank would be within the radius of influence (or cone of depression) of the boreholes during dry summers.

It was calculated that the flow velocity in the gravel is in the range 2.5-10m/d. Consequently the time taken for the effluent to get from beneath the septic tank to the borehole was estimated in the range 25-100 days if the gravel extended as far as the septic tank. However the travel time is likely to be less (it could be less than 20 days) as the gravel only extends to within 100m of the septic tank and the flow velocity in the limestones which underlie the septic tank is likely to be higher than in the gravels.

There is likely to be a thick unsaturated zone (up to 15m) beneath the septic tank site. However this zone is likely to consist mainly of fissured limestone and have little or no filtering action.

A4 AQUIFER PROTECTION SCHEME

The septic tank is in zone 1B of the aquifer protection scheme. Septic tanks are not recommended in this zone. If exceptions are allowed, it makes it difficult for the local authority to prevent the location of future septic tanks in the area.

A5 ASSESSMENT

It was not possible to state conclusively whether the effluent would significantly contaminate the boreholes and cause a health hazard. This depends on the degree of treatment and attenuation that occurs to the effluent before it reaches the boreholes. However, the available evidence suggested that the septic tank would be a health hazard because:-

(i) The proposed septic tank is in both the recharge area and in the cone of depression of the boreholes. Consequently the effluent from the septic tank would flow to the boreholes and would be pumped into the public supply.

(ii) In view of the calculated travel time of less than 25-100 days for effluent to get to the boreholes and the elimination rate of bacteria and viruses in groundwater (see Section 3) it is possible for pathogenic microorganisms to reach the boreholes.

(iii) If effluent can reach the boreholes the main mechanism of attenuation is dilution, which can be estimated as follows:-

Pumping rate = $591m^3/d$

Estimated flow from septic tank = $0.8m^3/d$

Dilution = 0.8/591 = 1:740

Dilution would be sufficient to bring all the effluent consituents below the EEC limits with the exception of bacteria and viruses (See Section 2 for effluent quality). Consequently the effect of the septic tank is likely to depend largely on the treatment and attenuation of the effluent in the immediate vicinity of the septic tank.

(iv) A minimum of 1-2m of fine granular material lies between the pipe distribution system and the bedrock. As there is only 1m of overburden, this might not be sufficient. It is not possible to be conclusive on this aspect because a properly constructed pipe distribution system might give sufficient attenuation. However the risks are high. A soakage pit would be inadequate.

A6 CONCLUSION

It was recommended that permission should not be granted.

PAPER PRESENTED FOR INTERNATIONAL HYDROGEOLOGICAL ASSOCIATION

(The Irish Branch)

AT: PORTLAOISE on the 7th April, I987.

SEPTIC TANKS - PUBLIC HEALTH ASPECTS

BY: Anne Deacon, Senior Environmental Health Officer,

South Eastern Health Board.

From a public health viewpoint and having regard to groundwater septic tanks can be dynamite. In fact my first recollection of septic tanks are tied up with dynamite.

Over I7 years ago, my parents got planning permission to build their house. Solid rock (slate) near the soil surface provided natural foundations for the house but no hole for the septic tank. Two Gardai stopped traffic on the adjacent roadway while dynamite split the rock and blasted a hole.

Much more exciting than doing a percolation test and trial hole beforehand. In fact my younger sister and I thought we were on a film set.

For the well, a local hydrogeological practitioner (a water diviner) struck water uphill of the house and a borehole was sunk. The next winter the intermittent water table rose and caused ponding in the soakpit and a line of springs to appear behind the front wall of the house.

Some slight modifications were deemed necessary.

I. The springs were piped out through the front wall of the house.

2. The kitchen sink water pipe now enters the percolation area through a grease trap.

3. The soakpit has evolved through time into a raised percolation area (without distribution pipes).

4. The percolation area has been planted with grass and shrubs.

FROM THE ABOVE INCIDENT IT FOLLOWS:

I. It is folly to grant planning permission without proper preliminary site investigation.

2. Even if a site is not suitable for a standard septic tank and percolation system it can often work with modifications. However, dynamite should not be necessary and all modifications cost extra.

Almost all cases of groundwater pollution caused by septic tanks which come to the notice of Environmental Health Officers (i.e. Health Inspectors) could have been prevented if the septic tank and percolation area were planned and built with individual site conditions and groundwater protection in mind.

Due to the time limit I will only deal with a few main points.. I have not gone into detail on any point but can do so during discussion if anyone wishes. I will not deal with special situations, like karst topography. I have made the presumption that everyone is familiar with SR6:I975

"Recommendations for Septic Tanks Drainage Systems for Single Dwellings" by the IIRS.

I will concentrate on prevention techniques in practical everyday use rather than cures or the theory or biology of systems.

Public health experience is this country and abroad has provided documented cases of illness e.g. I,200 cases of gastroenteritis caused when a city well was polluted by a septic tank I50' away in Richmond Heights, Florida. (McCoy & Ziehei 1 I977)

Environmental Health Officers (E.H.O.S.) deal with septic tanks at :

(a) Planning application stage.

(b) When they pollute public or private drinking water supplies e.g. public well supplying I00 people was polluted when a standard planning permission to SR6:I975 specifications was granted. The percolation area was constructed within 30' of the boundary of the site which was also the pumphouse wall with very predicable results.

(c) When percolation areas become clogged or waterlogged and

(i) The general public ask for advice.

(ii) When they don't ask for advice and pipe the effluent into a drain or roadside ditch and create a public health nuisance in so doing and fin ally when neighbours fall out and tell.

However, most neighbours don't fall out or have similar problems and polluted wells may only cause visitors, rather than longterm users, to get sick so E.H.O.'S only deal with the tip of the iceberg as regards malfunctioning sewage systems.

A problem situation usually involves the E.H.O.in applying first principles rather than trying to fit any particular standard.

Ist PRINCIPLES:

Groundwater should be potable for drinking water purposes, i.e. it should not be chemically polluted or contain pathogenic bacteria.

Sewage effluent from domestic dwellings or larger establishments contains bacteria and chemical pollutants which are not killed or broken down completely in the septic tank. Even in China where there is often a retention time of up to 70 days before spreading septic tank liquor on land, public health problems occur. (Watt. I984).

Therefore, secondary treatment in the form of a properly designed, constructed and maintained percolation area is essential.

The best stage to involve an E.H.O. is at the planning stage. Unfortunately, this does not happen in all counties.

There is a certain amount of basic information needed to reach a decision with regard to a planning application for a septic tank system.

I. A site map. Preferably, this should be of a scale of I:500 and show all buildings, wells (including disused wells), septic tanks and farmyard developments within I000' of the site.

2. A site inspection including vegetation and topography.

3. A trial hole 6' 6" deep. This gives both water table depth and a soil profile.

Where An Foras Taluntois county soil maps and bullentins are available these are very useful in indentifying the soil association involved. However, these maps are only available for five counties and are not large enough in scale. This is why Donal Daly's proposal with regard to simplified geology, depth of bedrock and aquifer maps would be endorsed fully by those involved in planning. However, these maps would not obviate the need for on-site inspection, as soil conditions can vary, sometimes dramatically, within a site giving an entire range of percolation rates from $t < 1$ in one corner of a site to $t > 60$ in the other corner.

Where $t < 10$ one usually advises the applicant that their well is particulary susceptible to pollution, even if it is I00' away and uphill of the percolation area. A groundwater map in this situation would probably help in providing some more concrete advise than the above.

4. The result of a certified percolation test in the exact location where the percolation area is proposed.

Results should include the soil type, water table level, weather conditions and percolation rates.

The percolation test in SR6:I975 is impractical because it is too time consuming.

The Test used by most officers depends on a mixture of experience. local knowledge and observing the percolation rate at the site.

Applicants are asked to dig a hole I' square by 2½' to 3' deep. Sometimes in areas where fraud is suspected the officer may have to supervise digging. If the soil has not been saturated it is necessary to allow for this before taking measurements of the percolation rate. Knowledge of local conditions and the soil association is used to judge when the true rate occurs. Otherwise, tests would require more hours than are available in a working day.

When doing a percolation test one usually interviews the landowner or applicant. Landowners can be very accurate about drainage in a field at different seasons and whether the land is heavy (clay) or light (sandy). It should be borne in mind as well that farmers usually sell their worst land for building.

Doing a percolation test provides an opportunity for some environmental health education. The applicant should be briefed on groundwater protection, septic tank and percolation area construction and maintenance. Often applicants only read whether permission has been granted or refused, they do not study conditions in depth and have not a copy of SR6:I975 to consult. Therefore, the above opportunity should not be wasted.

SR6:I975 was a milestone, but in the light of practicial experience should now be revised in certain areas.

I. THE DISTRIBUTION BOX.

A perfectly constructed distribution box prevents overloading of one side of the percolation area. However, practice very rarely reaches perfection and rather than promoting SR6:I975 or any similar standard builders usually try to persuade their clients to use inferior prefabricated tanks followed by soakpits. Hopes for the future appear dim when one finds AnCo training builders on a Health Board project and teaching them to build a bathroom first and then call in an E.H.O. to "make the water go away" from the hole into which they wish to place the septic tank. This when they were instructed to call an E.H.O. in to do a trial hole and percolation test before building.

Given this situation it is easier to construct a T-pipe system accurately and ensure proper distribution in this way.

2. EVAPO-TRANSPIRATION.

Plants absorb moisture and nutrients. They use (from the soil in which they grow) the nutrients for growth and they use the water for transport within the plant and lose some of it to the atmosphere through transpiration and evaporation. To promote this process in a percolation area plastic sheeting should be excluded. Building paper or straw which decay to form a permeable humus layer should be used instead.

3. VENTILATION PIPES AT THE END OF DISTRIBUTION TRENCHES.

These are impractical in any garden and a danger to toddlers and small children and should be dispensed with.

From the above, it follows that the bulk of SR6:I975 is still a perfectly good guideline for use in planning.

MODIFICATIONS:

I. To obtain distance requirements the site may have to be enlarged e.g. one quarter of an acre for septic tank only, half an acre for septic tank and well.

2. If the water table is too high drainage may solve the problem but this may involve the whole field rather than just the site.

3. Another solution used is the creation of an artificial sump to lower the watertable in the made-up percolation area.

3. IF A PERCOLATION TEST FAILS:

(a) It may be due to a perched watertable over an iron pen or other impermeable layer in which case breaking up this layer cures the percolation problem. This layer should be visible in the trial hole.

(b) A made-up or semi-raised or raised percolation area may be necessary using imported soil. The size of the site may have to be increased up 0.9 of an acre for a single dwelling. Large septic tanks need very large percolation areas. These can take up quite a portion of land especially when the reserve area is also included.

Detailed but adaptable guidelines for all these modifications have been drawn up by E.H.O.'s and have been in use for some yeaars, certainly since I980.

RESERVE PERCOLATION AREAS.

We have not found it necessary to specify that these should be constructed at the time of building but we have had cases of failure of percolation areas where we have supervised the design and construction of an alternate system in the reserve area of land. This is coupled with a strict warning to empty the septic tank annually. There has never been a recurrance.

SEPTIC TANKS

I have very little to say about tanks themselves other than to endorse the SR6:I975 design. Tanks should be watertight and the inlet and outlet pipes are usually what cause trouble. The tank should also be emptied once a year.

While it is said that necessity is the mother of invention, so too is the man in the street as anyone dealing with the public soon finds out to their cost. The examples are so good one does'nt even have to exagerate. So it is that one finds a septic tank in a bog with a pump attached to drive the effuent and a large volume of groundwater to an adjacent stream, which in turn pollutes a shallow well within 30' of it 500 yards downstream. The fact that the well is surrounded by three septic tanks one of which is only 40' away turns out to have no bearing on the pollution problem other than to confuse the investigating E.H.O. These types of situations; and those where the groundwater flows in directions opposite or perpendicular to surface water and ground topography; or where it takes groundwater seven months to travel 300 yards as the crow flies only serve to convince all E.H.O.'s that groundwater "moves in mysterious ways". Therefore, in endeavouring to solve the public health problems caused by septic tanks they would gratefully accept hydrogeological information in any form.

The second vehicle of planning is the County / City / Urban Development Plan. Perhaps the next set of these plans should incorporate groundwater policies.

I. By sterilizing land within the vicinity of public boreholes and insisting on a hydrogeological survey before considering an exemption.

2. By promoting a serviced village policy in rural areas rather than allowing dense ribbon development with septic tanks.

3. By insisting that all urban septic tanks be properly decommissioned once a public sewer is made available. Indeed this should be a standard condition on any planning permission near an urban area.

Environmental Health Education is also important. We find the general public very apathetic with regard to septic tanks, but absolutely fanatical about contaminated drinking water. One therefore has to stress the connection between the two, to ensure the public's attention.

We have never approached the builders directly, only through their consumers. Perhaps the time has come to tackle the problem more directly by approaching the builders themselves.

CONCLUSION:

Percolation areas of proper design and adequate size adapted to the individual site are a necessity with every septic tank system. The planning application stage is the time to ensure this happens.

With regard to public health septic tanks can be dynamite but there is no need for them to be so, if proper attention is given at the planning stage, and Environmemtal Health Education is provided to the public

SEPTIC TANKS AND GROUNDWATER - SOME RECENT IRISH RESEARCH

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SEPTIC TANKS AND GROUNDWATER - SOME RECENT IRISH RESEARCH

1 INTRODUCTION

In order for septic tanks to function in a manner that does not give rise to environmental contamination or health problems the tanks must be sited, operated, designed and maintained according to strict guidelines. Until recently little research on the impact of septic tanks on the environment of Ireland had been carried out. However, since 1985 personnel in the School of Science in Sligo Regional Technical College have been assessing groundwater quality in the County Sligo area and in the process have paid especial attention to the impact of point sources of contamination such as septic tanks, farmyard runoff and silage effluent.

The research in Sligo has taken the form of separate but related multidisciplinary projects involving an earth scientist, a microbiologist and graduates of the College's National Diploma in Environmental Science and B.Sc. in Environmental Science and Technology courses. Some of the projects have been completed but most are still in progress. This paper extracts those elements of the projects which have shed light on septic tank systems and their impact on the environment.

Unless otherwise stated all the data presented in this paper have been derived from analyses undertaken in Sligo R.T.C. and which have been carried out in accordance with commonly accepted procedures.

2 SEPTIC TANK SYSTEMS

A septic tank is a buried watertight container designed to receive wastewater from a house, to separate solids from liquids and to provide limited digestion of organic matter. The solids are stored in the tank and the liquid overflow is channelled to a seepage pit or percolation field from where it passes into the soil. The sewage from the house is flushed directly to the tank which may also receive washbasin and bathtub washings and kitchen waste (sullage). In some cases the sullage bypasses the tank and goes directly to the seepage pit or percolation field.

Septic tanks function primarily as settlement chambers and there is only limited reduction of the B.O.D. (Biochemical Oxygen Demand) of the wastewater in the tank itself. The settled solids (sludge) on the floor of the tank are partially digested by the action of anaerobic bacteria with the liberation of gases, principally carbon dioxide and methane.

The data in Table 1 show that the effluent from septic tanks is of poor quality and has the potential to cause serious contamination of waterbodies. In particular, the elevated B.O.D. and bacterial counts should be noted.

Within the tank there is only limited reduction of the polluting potential of the effluent and most attenuation occurs in the soil after the effluent has passed from the tank and through the seepage pit or percolation field. The soil therefore is an integral part of the process by which the effluent is reduced in strength and the authors suggest the use of the term 'septic tank system' to indicate that the septic tank and the surrounding soil should be regarded as a single unit.

The method by which the effluent is passed from the tank into the soil i.e. via a seepage pit or percolation field, is extremely important in determining the degree to which contamination of water bodies can take place. A seepage pit consists of a hole which is filled with stones and rubble and into which the effluent flows from the septic tank. The main drawback to this method of getting the effluent from the tank and into the soil is that the surface area of soil over which the effluent is spread is limited to the internal surface area of the pit and the soil very quickly becomes clogged. As will be noted in Sections 3 and 4 of this paper septic tank systems which use seepage pits frequently fail resulting in health and water contamination problems. Percolation fields (also known as adsorption fields or tile fields) are designed to allow an even discharge of the effluent through a large area of soil thus maximising the attenuating properties of the soil. This is achieved by allowing the wastewater to percolate through the perforations in a pipe distribution network to a gravel filled trench from where it spreads into the soil.

The extent to which attenuation of the effluent in the regolith (soil and overburden) takes place depends on the cation exchange capacity, the porosity, permeability and texture of the regolith, the thickness of the regolith beneath the site, the depth to the water table and the slope of the ground surface. Much research, particularly in the United States, has been directed at elucidating the relative importance of these parameters vis a vis the attenuation of septic tank effluent but until recently very little work had been carried out in Ireland to assess their importance under Irish conditions. In an attempt to gather some information on the mechanisms and amount of nutrient attenuation and bacterial migration and to develop methodologies for studying septic tank systems the authors carried out deep soil sampling and effluent analysis in the vicinity of a septic tank in the Sligo town area. In the investigation soil samples were collected from depths of 0.6m and 1.0m, where possible, and analysed physically, chemically and microbiologically. Sampling extended away from the seepage pit associated with tank for a distance of 9.0m along three transects. The effluent in the tank was also analysed physically, chemically and microbiologically. Part of this work has been reported in summary form (Doyle and Thorn, 1987).

The septic tank system is situated in the townland of Seafield North on the Knocknarea Peninsula in County Sligo (see Figure 1) and is located in an area with sandy soil which is underlain by coarse textured glacial drift. The depth to bedrock, which in this area is highly fissured Carboniferous limestone, is not known although regolith sampling to a depth of 1.0m did not encounter bedrock. The physical and chemical characteristics of the soil in the vicinity are presented in Table 2. A borehole 5m away from the seepage pit had a standing water level at the time of the investigation (late winter) of 9.8m below ground level.

The soil analysis showed that about 96% of the phosphorus in the effluent had been attenuated within 7m of the seepage pit. The attenuation of the sodium was less marked with about 65% reduction within 9m of the pit. The failure of the soil to maximise attenuation of sodium was shown by a concentration of 61 mg/l in an unpumped sample from the borehole. (A pumped sample would have been preferable but this was not possible). (In the Sligo area the background concentration of sodium in groundwater is usually between 7 and 12 mg/l). Problems in interpreting the concentrations of potassium in the soil meant that it was not possible to determine the rate or amount of attenuation of this constituent. However, a concentration of 138 mg/l in the borehole sample is in stark contrast to the usual background concentration of 1-4 mg/l in the Sligo area and suggests that attenuation was incomplete. Although ammonia (NH_4+) levels decreased rapidly with distance from the seepage pit the decrease appeared to be due to oxidation to nitrate rather than to adsorption. A concentration of 45 mg/l (nitrogen as nitrate) in the borehole suggested that the nitrate was lost largely by leaching. (The background concentration of nitrogen as nitrate is usually 1-3 mg/l).

The principal mechanisms by which bacteria are attenuated in the soil are filtration and adsorption. The coarse texture of the soil in the vicinity of the tank and the low cation exchange capacity meant that filtration and attenuation were reduced and the bacteria could move relatively freely. High numbers of coliform bacteria (6.0×10^3/g of soil) were recorded adjacent to the seepage pit but by 5.0m from the pit none were present. One interesting aspect of the investigation was that the number of bacteria detected in the soil in wet weather was significantly higher (up to ten times) than in dry weather. It would appear that heavy rainfall has the effect of flushing the organisms from the septic tank and through the soil. This flushing effect would be more pronounced in sandy/gravelly soils where infiltration is rapid and the mechanisms of filtration and adsorption are minimal.

The results of the microbial analysis also indicated that most of the bacterial migration was occurring at 0.6m depth in the soil and considerably less at 1.0m depth. This may be due to vertical differences in permeability but the scope of the study precluded the possibility of examining this aspect in more detail. Bacterial migration in specific zones has been reported by other authors e.g. Patterson et al (1971) and Bitton and Gerba (1984)

A significant point about the septic tank system investigated was that while the groundwater beneath the site was grossly contaminated there were no problems associated with the working of the system i.e. backing up, smells etc. It would seem therefore that an outward appearance of normality does not indicate that the system is working properly.

One of the main drawbacks to the above investigation was that it was not possible to obtain regolith samples from beneath the seepage pit and thus the vertical downward movement of the effluent through the bottom of the pit was not accounted for. One of the specific objectives of the above research was to try and establish a methodology for examining septic tank systems and research being conducted at present (see Section 5) has incorporated modifications that overcome the problem of not being able to sample beneath the seepage pit.

3 SITING, OPERATION AND MAINTENANCE OF SEPTIC TANK SYSTEMS

At present the main body of information on which Local Authorities base decisions to grant or reject planning applications and impose planning conditions for septic tank systems is the I.I.R.S. publication Recommendations for Septic Tank Drainage Systems for Single Houses (I.I.R.S. SR. 6, 1975) This publication lays out guidelines for the siting, design, operation and maintenance of septic tank systems. The Local Authority may and often do ask the Local Health Board to advise on the acceptability of proposed sites for septic tanks.

A recent survey of septic tanks (published in summary form already - Doyle, Henry and Thorn, 1986) revealed some very disturbing facts concerning the siting, operation and maintenance of septic tanks and the degree to which the I.I.R.S. recommendations were adhered. The survey included 42 randomly selected tank systems and the main findings are presented in summary form in Table 3.

Argueably the most significant finding of the survey was that 46% of all the tanks were found to be functioning ineffectively. The most common problems encountered were backing up and odours. None of the tanks used a percolation field as recommended by the I.I.R.S even though over half of the tanks had been constructed since 1975 when the guidelines were published. 47% of the tanks had never been desludged while 50% of the tanks were situated in areas where the density of the tanks was more than one per acre (0.4ha). In the opinion of a number of authors including Patterson et al (1971), Cartwright and Sherman (1974) and Yates (1985) a high density constitutes a potential health and pollution hazard. Many of the systems (38%) were located in areas susceptible to flooding; 31% were located in situations where there was less than 1.5m depth to bedrock and 24% had less than 1.5m of an unsaturated zone.

4 GROUNDWATER QUALITY IN COUNTY SLIGO WITH PARTICULAR REFERENCE TO CONTAMINATION BY SEPTIC TANK EFFLUENT

4:1 Introduction

During the summer months of 1985 a preliminary investigation of groundwater quality in south County Sligo was carried out (Thorn et al 1986). The main purpose of the investigation was to identify the agents of groundwater contamination and to select specific groundwater sources for long term monitoring. Section 4:2 below deals with the main findings of this investigation where relevant to the discussion in hand. Since August 1986 a number of wells and springs (7) have been monitored on a monthly basis. This longer term monitoring has shown that a number of the wells and risings are consistently contaminated and some of the findings of the monitoring to date are dealt with in Section 4:3. Also included in 4:3 are the summarised results of a survey which dealt solely with the microbiological quality of groundwater on the Knocknarea Peninsula. The final section (4:4) presents a few examples of situations in which the authors are certain or nearly certain that septic tank effluent is or has been a major cause of contamination.

4:2 Groundwater Quality in South County Sligo

The study in 1985 centered on the Owenmore and Unshin river catchments in south County Sligo (see Figure 1). The area is predominantly lowlying with few parts rising above 150m above sea level. With the exception of the northern part of the catchments, which are underlain by Pre-Cambrian metamorphic rocks, the rest of the catchments are underlain by lower Carboniferous limestones, sandstones and shales. These rocks are blanketed with glacial drift which for the most part is till. The soils of the region are principally grey-brown podzolics and gleys.

Fifty wells (both dug and bored) and springs were sampled. The results of the physical and chemical analysis showed that in general the water was of good quality and in only a few cases were E.C. guidelines for drinking water exceeded (European Community, 1980). The concentrations of nitrate-nitrogen, an ion of particular interest, were less than the E.C. Maximum Admissable Concentration (M.A.C.) of 11.3 mg/l and only one sample exceeded the E.C. Guide Level (G.L.) of 5.6 mg/l.

The microbiological quality of the water was not good. 67% of the samples were contaminated to some degree by either faecal coliforms or faecal streptococci. The presence of these organisms in the groundwater indicated that the contamination was of man or animal intestinal origin i.e. from septic tanks or animal manures or slurries. Faecal coliforms or faecal streptococci are not, in general, harmful to man (coliform bacteria are opportunistic pathogens so they may on occasion cause problems), they do however, by their presence in a water sample, indicate possible contamination by pathogenic bacteria such as *Salmonella spp.*, *Shigella spp.* and *Clostridium perfringens* pathogens and enteric viruses such as hepatitis.

The ratio of faecal coliforms to faecal streptococci in a water sample can tentatively help to pinpoint the source of the contamination. In human faeces faecal coliforms are present in far greater numbers than faecal streptococci with an approximate ratio of 4:1. Farm animal faeces on the other hand contain larger numbers of faecal streptococci with a ratio of 1:5 (Mara, 1974). The ratios calculated from the results obtained in the investigation indicated that approximately 50% of the contamination was due to human faeces i.e. septic tank effluent.

In one particular case near Coolaney (see Figure 1) gross contamination of a spring was noted to be taking place and the details of this case are given in 4:4.2 below.

The usefullness of the faecal coliform/faecal streptococci ratio in identifying the source of the contamination depends very much on the survival times of the indicator organisms in groundwater and soils. A recent study has suggested (Bitton et al, 1983) that *Streptococcus fecalis* may survive longer than *Escherichia coli* in soil and groundwater and research on this is at present being conducted in Sligo R.T.C. It is hoped that the results of this study will determine the usefullness of the ratio as a means of identifying groundwater contaminants.

4:3 Groundwater Quality in the Knocknarea Peninsula, Co. Sligo

Following the investigation in 1985 a number of springs and boreholes were selected to be part of a long term monitoring programme. Seven boreholes and springs were selected for the programme and their locations are shown on Figure 3. As can be seen not all of them are located on the Knocknarea Peninsula, however, most of those boreholes and springs which have consistently shown contamination are located on the peninsula and so have been dealt with here.

Of the boreholes and springs selected for long term monitoring nos. 1, 5, 6 and 7 are located on the Knocknarea peninsula or in its vicinity. Table 4 gives the mean and maximum values for the physical and chemical parameters that were recorded in these groundwater sources between August and December 1986. (In the early part of the programme monitoring was weekly but since November 1986 monitoring has been monthly). Microbiological analysis of the samples has been carried out on three occasions since August 1986; in mid-September and early November 1986 and in mid-January 1987.

The Knocknarea peninsula is an area of mixed development with grassland farming and non-farming housing. A variable thickness of glacial sands and gravels overlies fissured Carboniferous limestone. In general, the nitrate concentrations reflect the fact that the farming is more intensive than in south County Sligo; the average nitrogen as nitrate concentration on the Knocknarea peninsula is about 3 mg/l whereas the 1985 study in south Sligo gave an average of about 1 mg/l. The E.C. G.L. of 5.6 mg/l for nitrogen as nitrate has frequently been exceeded although the M.A.C. of 11.6 mg/l has not been exceeded to date. Sodium (Na) and potassium (K) levels have varied considerably as has the K/Na ratio. Under natural conditions potassium levels in Irish groundwater are generally $<$ 3 mg/l and the K/Na ratio is usually $<$ 0.3. Potassium levels greater than 5 mg/l and K/Na ratios more than 0.3 have been taken to indicate contamination from local point sources of organic pollution. such as septic tanks and farmyard runoff (Daly and Daly, 1982). In a number of cases high potassium concentrations and K/Na ratios have coincided with elevated nitrate and total dissolved solid concentrations and high electrical conductivity indicating the likelihood that organic contamination has occurred. Chloride concentrations are in many cases a good indication of the presence of contamination from intestinal sources but the proximity of the sea means that there are high background concentrations of this ion thus precluding its usefullness as an indicator of contamination in this instance.

The microbiological analyses showed the presence of varying degrees of contamination in the four groundwater sources. Faecal coliforms, which are a much more reliable indicator of contamination than total coliforms, were not detected on the first sampling date while all the samples showed their presence on the second and third occasions. On the third sampling occasion a number of the groundwater sources had faecal streptococci present and one of the locations is dealt with in 4:4.2 below.

In February 1987 a microbiological survey of 13 groundwater sources on the Knocknarea peninsula was undertaken. Both risings and boreholes were sampled and the samples were analysed for total coliforms, faecal coliforms, faecal streptococci and total mesophiles. Eight of the samples were contaminated with total and faecal coliforms and all of the samples were contaminated with total coliforms. A number of the samples were contaminated with faecal streptococci and at the time of writing these results are being confirmed. It was noted that many of the samples contaminated contained high numbers of total mesophiles (up to 8.5×10^4 cfu's/100ml). Such high numbers are probably due to stimulated growth resulting from the presence of organic matter as a result of contamination - a fact that the presence of faecal coliforms and faecal streptococci would seem to bear out.

4:4 Specific Examples of Contamination from Septic Tank Effluent

4:4.1 Example A

(See Figure 1) A spring serving a farmhouse was visited by the authors in the summer of 1985. The spring was located in a small field in front of the farmhouse. On inspection the spring was found to contain large clumps of sewage fungus. Closer inspection of the site revealed that the septic tank system serving the farmhouse was 10m upslope of the spring and that indiscriminate spreading of farmyard manure was taking place in the vicinity of the spring. The physical and chemical analysis of the water showed it to be of moderate quality but the microbiological analysis revealed the extent of the contamination (350 cfu's/100ml faecal coliforms and the same for faecal streptococci). When the owner was asked if the well was being used he replied "No, only for domestic purposes"!

4:4.2 Example B

(See Figure 1) This location is the same as sampling location 1. This is a large rising on the shores of Lough Gill about 5km south-east of Sligo Town. The spring, which rises from fissured limestone, is better know as Tobernalt or the Holy Well and has been the site of local pilgrimages since Penal times. It is claimed that the consumption of the spring water has divine healing powers and large numbers of pilgrims visit the well annually.

The spring has been monitored by the authors since August 1986 and has been samplede on occasion by Sligo County Council. On a number of occasions elevated levels of nitrate (up to 5.6 mg/l nitrogen as nitrate) and total dissolved solids have been found. High electrical conductivity has been recorded and K/Na ratios up to 1.5. The microbiological quality of the water on each occasion that the authors have sampled has been poor with either or both faecal/total coliforms and faecal streptococci present. These results are in accordance with those obtained by Sligo County Council who have on occasion deemed the spring to be unfit for human consumption.

The spring is located at the base of a steep limestone scarp on top of which there has been fairly substantial housing development in recent years. Each of the houses is served by a septic tank and there is little agricultural activity in the area. The authors are of the firm opinion that septic tank effluent is causing the contamination of the well.

4:4.3 Example C

(See Figure 1) A septic tank system serving approximately 200 persons in a large institution on the shores of Lough Gill was investigated in 1985. The system consisted of one main septic tank, a smaller subsidiary tank and a seepage pit receiving the outflow from both. The pit was found to be completely clogged due to overloading of the system. Extremely high numbers of coliform bactera were detected in the soil downslope of the seepage pit (7.7 x 10^5 faecal coliforms/g of soil). These numbers exceeded by a factor of 100 those detected in the soil in the system investigated in Seafield North Townland. Algal blooms are frequently reported from the northern shore of the lake in the vicinity of the institution. A new waste disposal system is currently being constructed.

5 CONCLUSIONS

In the foregoing sections the authors have shown that contamination of groundwater by septic tanks has and is occurring. The authors are of the opinion that many of the problems caused by septic tanks could be minimised if there was strict adherence to the guidelines laid down by the I.I.R.S. In many instances Local Authorities stipulate that septic tanks should be constructed according to the I.I.R.S. guidelines however, lack of follow up inspections means that in many cases inadequate attention is paid by the developer to the installation of the septic tank and soil disposal system.

While the authors believe that the I.I.R.S. guidelines are in general adequate we feel that any future revision should incorporate guidelines that have specific regard to the protection of groundwater e.g. depth to bedrock and closeness to groundwater sources.

At present, research on groundwater and septic tanks in Sligo Regional Technical College is in three main areas. First, one of the authors (H. Henry) is investigating the mechanisms of septic tank effluent attenuation and bacterial survival with a view to providing simplified procedures for determining the suitability of sites for septic tank systems. (This research is leading to a Masters in Science). Second, long term monitoring of groundwater quality is continuing. The aim of this research is to provide a database of groundwater chemistry data for use in future groundwater projects and to enable short term fluctuations in groundwater chemistry to be examined. Third, a number of small scale projects are attempting to identify chemical parameters which might be useful as indicators of specific types of groundwater contamination.

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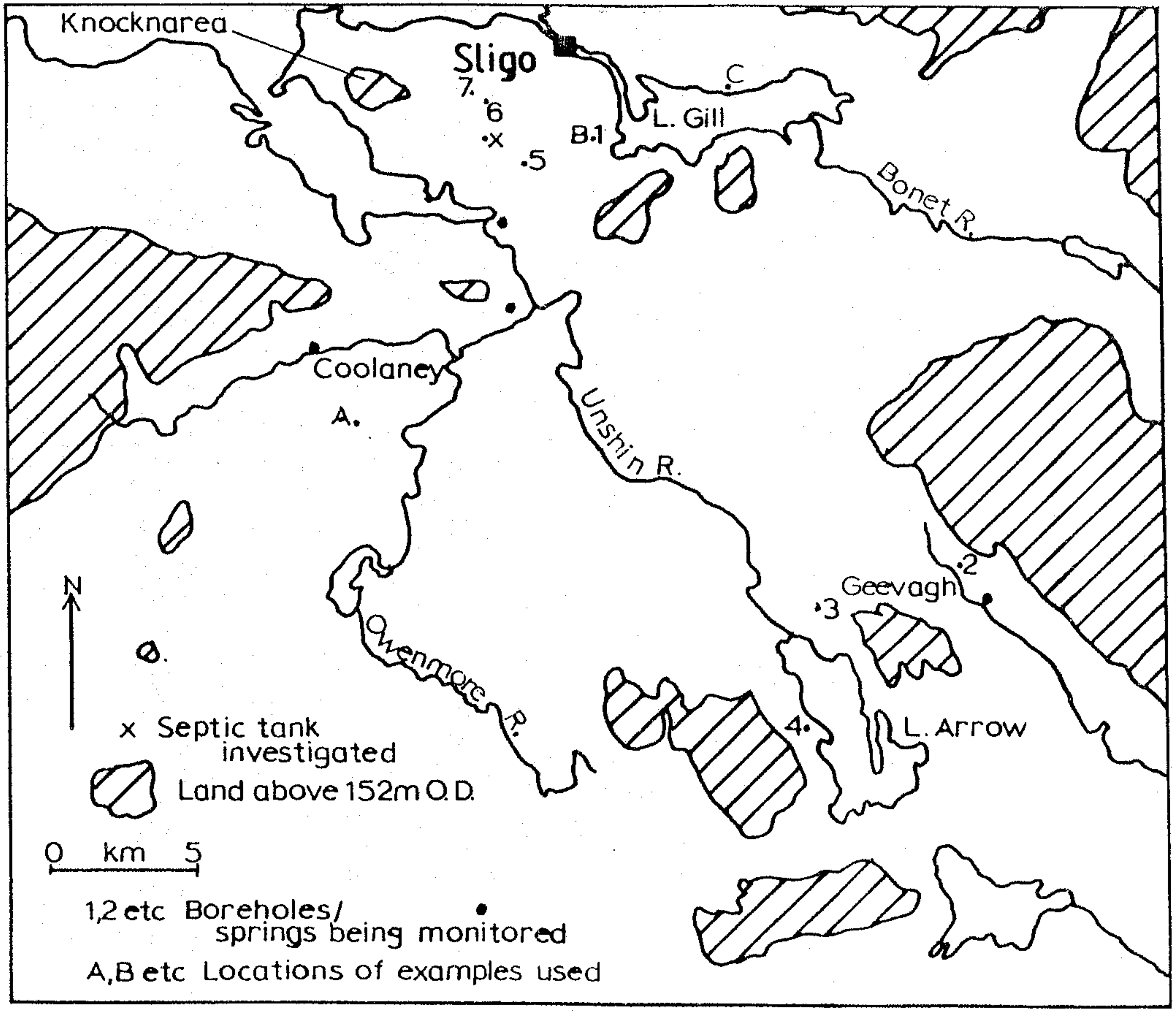

Figure 1 General location map

Table 1

Septic Tank Effluent Composition

Parameter	Concentration
Conductivity	900 - 1674 umhos/cm at 25^{o}C
pH	7.0 - 8.5 pH units
Hardness (as $CaCO_3$)	200 mg/l
Alkalinity (as $CaCO_3$)	125 mg/l
Potassium	22 - 87 mg/l
Sodium	95 - 152 mg/l
Available Phosphate	52 mg/l
Chloride	57 mg/l
Nitrogen as Ammonium	21 mg/l
B.O.D.	266 mg/l
Total Coliforms	1.8 x 10^{7} cfu's/100ml [1]
Faecal Coliforms	1.2 x 10^{6} cfu's/100ml [1]

[1]Based on analyses from three tanks.

Table 2

Physical and Chemical Properties of the Soil in the Septic Tank System in Seafield North Townland, Co. Sligo

Textural Analysis	%
Gravel	50
Sand	32
Silt	9
Clay	9

Parameter	
Cation Exchange Capacity	10.16 meq/100g.
Porosity	36%
Percolation Rate	0.07 mm/sec.
pH	7.45 pH units.
Organic matter	5.7%

TABLE 3
Main Findings of Septic Tank Information Survey

1 Septic tank construction:

	%
In Situ concrete	86
Prefabricated	12
Fibre glass	2

2 Number of people served by system:

	%
Greater than 4	90
Less than 4	10

(The I.I.R.S. recommend a minimum design population of 4)

3 Thickness of regolith above bedrock:

	%
Greater than 1.5m	33
Less than 1.5m	31
Don't know	36

4 Thickness of unsaturated zone:

	%
Greater than 1.5m	43
Less than 1.5m	24
Don't know	43

5 Septic tanks situated in areas susceptible to flooding:

	%
Yes	38
No	62

6 Septic tanks giving problems (e.g. odours, backing up):

	%
Yes	46
No	54

7 Septic tanks located close to groundwater source (200m or less):

	%
Yes	62
No	38

8 Septic tanks located close to groundwater source and giving problems:

	%
Yes	74
No	26

Table 3 Cont.
Main Findings of Septic Tank Survey

9 Frequency of sludge removal:

	%
Seldom (> 5 years)	36
Regularly (2-5 years)	17
Never	47

(The I.I.R.S. recommend desludging once a year)

10 Type of soil disposal system used:

	%
Seepage pit	90
Percolation field	0
None	10

11 Density of septic tanks:

	%
Less than one per 0.4ha	50
More than one per 0.4ha	50

13 Tanks located in areas of high density giving problems (e.g backing up, water contamination):

	%
Yes	32
No	68

14 Composition of waste entering the tank:

	%
All household waste	60
Sewage	40

15 Age of septic tanks:

	%
<5 years	20
5-10 years	41
11-15 years	14
>15 years	25

Table 4

Mean and Maximum Concentrations of Physical and Chemical Parameters in Sampling Locations 1, 5, 6 and 7

	Location 1		Location 2		Location 3		Location 4	
Parameter	$\bar{x}$	max	$\bar{x}$	max	$\bar{x}$	max	$\bar{x}$	max
Temp.	10.5	11.0	10.5	12.0	---	---	10.5	11.0
pH	6.4	6.5	6.4	6.6	6.4	6.7	6.4	6.7
Cond.	428.0	560.0	565.0	732.0	595.0	851.0	558.7	752.0
Hardness	277.0	344.0	329.0	430.0	359.0	452.0	365.2	496.0
Alkalinity	114.0	143.0	151.0	174.0	158.0	184.0	164.0	180.0
Chloride	17.2	24.5	23.1	29.0	27.6	32.0	21.5	29.0
Sodium	11.6	16.6	15.3	16.9	17.1	19.0	16.4	19.7
Potassium	1.8	3.2	3.1	5.8	3.2	5.5	3.0	7.3
Nitrate (as N)	2.6	5.6	3.4	7.5	2.9	7.3	3.6	5.2
Sulphate	11.5	13.5	12.8	15.4	10.8	14.4	11.3	19.1
T.D.S.	343.0	446.0	408.0	634.0	343.0	642.0	427.0	718.0

All units in mg/l except Temp (^{o}C), pH (pH units) and Conductivity (umhos/Cm at $25^{o}C$)

Analysis of the samples for iron, manganese, magnesium and calcium is at present being carried out.

THE ASSESSMENT OF GROUNDWATER RESOURCES

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An earlier version of this paper was presented to
the Cork/Kerry branch of the
Institution of Engineers of Ireland, on 15/4/1982
at University College Cork.

Groundwater is an important natural resource, and most importantly a renewable resource. It is our responsibility to use it carefully and wisely, and to pass it on to the next generation in good condition, undepleted in quantity and unpolluted in quality. This is what is meant by groundwater conservation.

Groundwater conservation can be seen as being achieved by two principal means:

(a) Protection of groundwater from pollution

(b) Management of groundwater abstraction, which in turn depends on accurate assessment of the size of the groundwater resource.

This paper outlines some approaches to the subject of groundwater resource assessment.

While resource assessment is mainly concerned with the volume of the resource, the quality of the groundwater is also relevant, since the water quality may govern the use of the water. In Ireland, our groundwater is mostly of good quality and can be used for almost any purpose, but elsewhere in the world this is not so. Especially in arid countries, there may be a wide range of water quality, from very pure to brackish or saline. Only the purer water would be good for irrigation, but brackish water might be acceptable for stock watering or for cooling purposes. In such countries the resource assessment must take account of the water quality.

The main objective of resource assessment can be summed up by the term "Safe Yield of an aquifer". The term 'Safe Yield' is the acceptable limit of annual abstraction from an aquifer. Originally it was taken as being equal to the annual recharge to the aquifer, but nowadays it is defined in a more subtle way as "the maximum annual yield from the aquifer which can be abstracted without adverse consequences". Depletion of the resource is only one of the possible adverse consequences.

An alternative concept is that of the 'Optimal Yield' of an aquifer, which is calculated on the cost/benefit principle. In many cases this would be less than the Safe Yield, but in some cases it could be greater, i.e. it may be possible to show that depletion of the resource is justified by the cost/benefit ratio.

In describing how the 'Safe Yield' is calculated, the assumption is made that sufficient information is available on the aquifer, as to its area, thickness, depth to water table, permeability, storage coefficient (storativity), etc. The value of the assessment obviously depends on the accuracy of this information.

The key to the assessment of the 'Safe Yield' of an aquifer lies in the identification of the principle constraint on abstraction - i.e. what is the critical factor which limits the quantity of water which can be removed from the aquifer over a given period without causing unacceptable consequences?

Eight potentially important constraints can be listed:

A. Available Recharge

B. Maintenance of Streamflow

C. Available Storage

D. Aquifer Throughflow

E. Seawater Intrusion

F. Water Quality

G. Subsidence

H. Economic Constraints

A. <u>Available Recharge</u>

This is usually the most important constraint - if we can calculate the quantity of water which recharges a given aquifer in an average year, then this will set an upper limit to the quantity which can be abstracted from that aquifer, on an annual basis, without depleting the groundwater storage. This quantity of recharge therefore sets the fundamental limit to the exploitation of an aquifer.

However, the situation need not be so simple, especially in a humid country like ours. In Ireland, a good deal of the rainfall which could be available for recharge is unable to enter groundwater storage because the aquifer is already full to overflowing - we can refer to this as 'rejected recharge' - and it simply contributes to the flow of surface streams. When an aquifer is developed, additional storage space is created in the aquifer by lowering the water table, and more recharge can be accepted. Thus by developing the aquifer we can increase the annual recharge and, effectively, increase the resource.

Groundwater abstraction persistently in excess of the average annual recharge will gradually draw down the water table, and thus deplete the resource. This is often referred to as "groundwater mining", i.e. treating the groundwater as a mineral deposit, and eventually exhausting it. Sometimes this can be justified on cost/benefit grounds but it requires very serious consideration.

Two kinds of natural recharge exist - known as 'Direct' and 'Indirect' recharge, though these terms are somewhat misleading because 'Indirect Recharge' can often take place much more quickly than 'Direct Recharge'.

Direct recharge is that part of the precipitation which percolates directly from the land surface down to the aquifer.

Indirect recharge is that part of the precipitation which first becomes surface run-off and later recharges the aquifer through the bed of a stream or lake or via sinkholes.

There is also 'Artificial Recharge' which is surface water artificially diverted to recharge an aquifer via recharge wells or basins. It is unlikely to be of great significance in Ireland for some time but could be useful in small areas of intensive abstraction.

Recharge can be estimated by several different methods; it is always preferable to use more than one method and compare and possibly average the results.

(1) By direct measurement:

Direct measurement of infiltration, by means of lysimeters or percolation gauges, has been in use for many years, but with only limited success. The main problems lie in constructing gauges which correctly simulate natural conditions, and in extrapolating the results over large areas of widely varying geology, soil type and vegetative cover. At best, it seems that instrumental methods can only assist other methods, and not replace them.

(2) Estimation of infiltration:

In this country we have fairly reliable measurements of rainfall, provided by the Meteorological Service, and good estimates of potential evapotranspiration. By subtracting the evapotranspiration from the rainfall we are left with a quantity we can call Residual Rainfall (also called Effective Rainfall or Potential Recharge). This Residual Rainfall is the quantity which is available to replenish soil moisture, to recharge aquifers, and to feed streams. The proportion of the Residual Rainfall which goes to recharge aquifers will depend on several factors - the topography, the type and thickness of soil and overburden, the nature of the aquifer, etc. If we know enough about

these factors, then we can estimate this proportion ('Infiltration Factor') and thus quantify the annual recharge to the aquifer.
Thus, Recharge = Residual Rainfall x Infiltration Factor.

This kind of approach has been used for some time, sometimes using total rainfall instead of residual rainfall. Boswell (1943) suggested that recharge comprised 40% - 50% of total rainfall in the Chalk and Triassic Sandstone of England. In the same paper he referred to the common usage of the very round figure of 10 inches for the average percolation value in areas of Chalk and Triassic Sandstone outcrop receiving 25 - 30 inches per year of total rainfall.

(3) Examination of Stream Hydrographs:

Where we have detailed run-off measurements for a catchment which includes substantial areas of aquifer, the groundwater component of total run-off can be estimated by examining the stream hydrograph, and drawing in the 'groundwater curve'. By measuring the volume of water represented by this curve, a figure can be obtained for the total natural groundwater discharge from the catchment over a given period.

In any given year, the groundwater discharge will depend on the climatic factors in that year. In a dry year, the groundwater component of total flow will probably be larger than recharge, so there will be a reduction in groundwater storage in the catchment, reflected by a falling water table. In a wet year, recharge will likely be higher than discharge. However, over a period of some years, recharge and discharge should be equal. Hence an average value of groundwater discharge for a catchment should equal the average recharge to the aquifers in that catchment. This technique is easiest to use where the catchment geology is simple and the area of aquifer relatively large. In more complex areas, or where the aquifer is small relative to the catchment, it becomes more difficult. The procedure appears rather subjective but used sensitively and with some cross-checking it can be very valuable. The accuracy is much increased if actual water table measurements are available, and if the storage coefficient of the aquifer is known.

(4) Water Balance:

A further development of the above methods is to construct a water balance for a catchment, in which the recharge is the unknown which can be estimated by solving an equation or series of equations.

B. Maintenance of Streamflow

This is probably the second most important constraint. Its significance will depend on the size of the aquifer in relation to the catchment. Where an aquifer makes a sizeable contribution to the streamflow, large abstractions of groundwater can lead to significant reductions in the streamflow, especially in summer.

To take an extreme example, many streams in England drain catchments which are entirely underlain by chalk, and virtually the entire flow of the streams is derived from groundwater. In these cases, streamflow will be markedly affected by major abstraction schemes, and streams could dry up entirely for some part of the year. This is clearly unacceptable and has led to the concept of the Minimum Acceptable Flow (M.A.F.). In England it became mandatory for a Regional Water Authority (formerly River Authority) to maintain the M.A.F. in a stream, and if the natural flow fell below this, owing to abstractions, then compensatory water had to be fed into the stream from specially drilled boreholes.

In Ireland we would be unlikely to have such critical conditions. Nevertheless, in dry years such as 1975 and 1976 the summer flows in many rivers became very low. With effluent loads increasing in many rivers, it is important to ensure that flows are not reduced to unacceptable levels. Hence the contribution of an aquifer to river flow needs to be taken into account. It is likely to be most critical in small catchments near major centres of population or industry.

C. Available Storage

In most aquifers, the volume of available water in storage within a given area is at least several times larger than the annual recharge. The excess storage ensures that, in a dry year, groundwater abstraction can exceed the recharge for that year, the deficit being made up by additional recharge in a subsequent wet year. The storage thus allows for a hydrological 'overdraft facility'. However, in some aquifers, total storage space is relatively low compared with annual recharge, because:

(i) The aquifer is very small in extent or in thickness (e.g. a small gravel deposit in a valley), or

(ii) The aquifer has a very low storage coefficient, or

(iii) The aquifer is very well drained, so that most of the water is not retained for more than a few days or weeks (e.g. karst uplands such as the Burren).

In these cases, the available storage capacity affects the safe yield.

Where the available storage capacity is only a little more than the average

Thus: $P = I + ET + RO$

or $P = ET + RO + R_1 + R_2 \pm U \pm SG \pm SS$

where
P = Precipitation
I = Infiltration
ET = Evapotranspiration (Actual)
RO = Surface Runoff
R_1 = Interflow
R_2 = Groundwater discharge
U = Underflow
SG = Change in Groundwater Storage
SS = Change in Soil Moisture Storage

This leads into the realm of mathematical modelling, where a computer model is used to simulate the hydrology of an aquifer or catchment and match theoretical behaviour against observed behaviour. Such modelling techniques are rapidly becoming more important, but they depend for their accuracy on good field data.

Indirect Recharge is important in many aquifers, particularly in arid or semi-arid countries, where the water table is often below stream level and there is a gradient from the river into the aquifer. In Ireland such conditions are less common, though by no means unknown in summer. Three points are worth noting:

1. By indirect recharge an aquifer may be recharged by rain falling on adjacent upland areas. This is important, for instance, in the limestone valleys of South Munster, where the aquifer lies in the valley bottom and can be recharged by surface water flowing off the impervious slate/sandstone uplands on either side.
2. Indirect recharge can take place in summer, when direct recharge is effectively prevented by the presence of a soil moisture deficit. In Ireland it would often take place via sinkholes in limestone country.
3. As aquifers are developed, further indirect recharge can be induced, for instance by pumping from boreholes close to a stream.

Indirect recharge is difficult to estimate. In the case of sinkhole flows, the disappearing stream can perhaps be gauged. Losses from the bed of a lake or stream are very difficult to determine, though gaugings above and below the zone of recharge may be successful.

volume of annual recharge, the safe yield will be less than the average recharge and may be limited to the volume of recharge expected in a very dry year.

Where the storage capacity is even less than the minimum (dry year) recharge, then the safe yield will be limited to the actual extractable storage capacity.

Very similar principles in relation to surface water reservoirs have been described in the Manual of Water Supply Practice by Hobbs (1954), and it appears that the chart (Chart A) supplied in that book could be adapted for use with groundwater storage calculations.

D. Aquifer Throughflow

This may be the principal constraint in the case of a confined aquifer, or for an aquifer in an arid country where the recharge is derived from rainfall at a considerable distance, such as a mountain range many miles away. In either case, the Safe Yield may be governed by the quantity of water which can flow through the aquifer under abstraction conditions.

In order to calculate the throughflow, one needs to know:

(i)	The mass permeability of the aquifer	(K)	K x D = Aquifer
(ii)	Its saturated thickness	(D)	Transmissivity.
(iii)	Its hydraulic gradient under pumping conditions	(I)	
(iv)	The width of aquifer involved	(W)	

Then, by Darcy's Law,

$$Q = K \times D \times W \times I = \text{Throughflow.}$$

If the value for Q is less than the available recharge, then Q will represent the maximum available abstraction. An Irish example of an aquifer where this is the principal constraint is in the sandstones of the Castlecomer Plateau in Counties Carlow, Kilkenny and Laois.

E. Seawater Intrusion

This constraint applies to aquifers in coastal areas where the aquifer is in hydraulic continuity with the sea or a saline estuary. Since Ireland has a long coastline and much of the population lives near the sea, this constraint may be quite important, especially in such areas as Cork Harbour, the Shannon Estuary, South Wexford, Dundalk, Tralee, etc.

The Ghyben-Herzberg equation to predict the position of the seawater-freshwater interface is well known, and suggests that under natural conditions seawater will not normally penetrate far into an aquifer. However, the Ghyben-Herzberg formula relates salt and fresh water under static conditions. In a number of ways the natural situation is somewhat different:

(i) The natural hydraulic situation is not static but dynamic; water is flowing out of the aquifer into the sea. This has the effect that the interface is somewhat deeper than as predicted by Ghyben and Herzberg.

(ii) The sea level varies with the tides, while the water table varies with the season. Hence the interface is not fixed but mobile, moving according to the relative hydraulic heads. There is also some dispersion and diffusion of the salt. Consequently the 'interface' is in reality a zone of mixing which may be quite broad.

(iii) The nature of the sea-bed may be very influential. In many cases it may be covered by a thickness of rather silty, poorly permeable sediment. Moreover, such loose sediment will tend to have a lower permeability in a downward direction than in an upward direction. This tends to favour groundwater flow out of the aquifer and to discourage seawater flow into the aquifer.

(iv) In limestone areas, the aquifer is often highly fissured or karstic; the fissures or caverns provide better opportunities for seawater intrusion than the intergranular-flow type of aquifer normally considered in hypothetical calculations. Even under natural conditions, seawater intrusion can take place at high tide up to a couple of miles inland, e.g. near Kinvara, Co. Galway.

In estimating the Safe Yield of a coastal aquifer, the essential consideration is that at all times the water table near the coast must be maintained at a sufficient elevation to ensure that groundwater outflow takes place and seawater can not intrude. This may be achieved by limiting abstractions.

F. Water Quality

This could be regarded as a variant of the Saline Intrusion Case. It may happen that by abstracting heavily from an aquifer one may cause leakage into the aquifer from another formation containing water of poor quality - e.g. with high content of salt, or sulphate, or some other unwanted substance. This would then limit the abstractable volume - the Safe Yield - to what could be abstracted without causing such leakage.

G. Subsidence

The major reason for subsidence in connection with groundwater abstraction is probably poor well construction, which can lead to pumping of sand, causing subsidence in the immediate vicinity of the well. However, in certain circumstances, heavy abstractions may cause more serious subsidence over a general area. Two general cases may be given:

(i) Removal of water from fine compressible sands, or from gravels/sands underlying or interbedded with compressible sediments, may lead to consolidation or shrinkage of these sediments, causing general subsidence over an area. This has happened, for instance, in Calfornia (San Joaquin Valley, c. 9m subsidence) and in Mexico City (c. 9m subsidence). The process is largely irreversible.

(ii) In some cavernous limestone areas, removal of water (and perhaps consequent removal of sediment in fissures) may remove vital support from the rocks, leading to collapse. This has been noted especially in mining areas where very severe dewatering has taken place. Such collapse has been well documented in Florida and Alabama, USA, and in South Africa.

H. Economic Constraints

Abstraction of the total available yield may not be possible because it would entail unacceptably high expenditure. For instance, it might require too many boreholes (e.g. in a very thin or poorly permeable aquifer), or the pumping costs might be too great (owing to a very deep water table, or high drawdowns). In such cases the yield will be limited to that which is economically justifiable.

Groundwater Resources in Ireland

In 1978/79 the Geological Survey of Ireland carried out a project on contract for the European Commission, whcih involved defining the aquifers of the country as far as possible, and then calculating the available resources of these aquifers. The calculation was principally by estimation of recharge. The need to meet stream flow was not taken into account, but the saline intrusion constraint was applied where necessary. Existing abstractions were subtracted from the recharge estimate, to arrive at a figure for 'surplus resources'.

The resulting figures were very approximate, but they represent the first attempt to carry out such an exercise in this country (Wright et al. 1982).

Table I summarises the figures we arrived at, showing that the surplus resources are very large. Even when they are reduced substantially to allow for maintenance of stream flow and other constraints, it is clear that the available resources are still very large in relation to the total water demands in this country.

TABLE I

SUMMARY OF GROUNDWATER RESOURCES BY REGION

WATER RESOURCE REGION	AREA	AREA OF AQUIFERS	ESTIMATED ABSTRACTIONS	ESTIMATED SURPLUS RESOURCES	
	Km^2	Km^2	Mm^3/yr	Mm^3/yr	mm/yr over region
Eastern	7622.5	1392	6.08	197.4	25.9
South-Eastern	12768	4240	20.7	763	59.6
Southern	11406	1474.5	25.15	603.6	52.9
Mid-Western	7508	2942.5	8.43	492.1	65.5
Shannon	10520	3124.9	16.69	471.7	44.8
Western	9615.5	4446	6.23	643.3	67.0
North-Western	9460	1245.5	6.3	202.5	21.4
TOTAL:	68900	18865.4	89.58	3373.6	49.0 over country

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<u>INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS</u>

<u>7TH ANNUAL SEMINAR - 7 & 8 APRIL 1987</u>

CAMROSS - ADAMSTOWN REGIONAL WATER SUPPLY SCHEME, CO. WEXFORD

By: Mr. K. O'Dwyer B.E. of K.T.C. Hydrogeological and Environmental Services.

Summary

Wexford County Council proposes to develop a regional water supply scheme to serve the rural areas between the main population centres of Wexford, New Ross and Enniscorthy. The source of this scheme is to be a well field located in a bedrock aquifer just south of Adamstown which is part of the regionally important Duncannon Group Volcanic Aquifer.

Groundwater investigations at Adamstown began in 1979 - '80 when two trial wells (31 - 1 & 2) were drilled to locate a source for a proposed local group scheme. These wells indicated that the Adamstown area was underlain by a volcanic aquifer capable of individual well yields in excess of 1,000 m3/day. This result was confirmed in 1982 by a County council cottage well (35-10) which was test pumped at a rate of 2,000 m3/day. The present study, involving the drilling of 4 trial wells and a series of pumping tests was designed to estimate a minimum yield for the aquifer at Adamstown and establish the outputs of the various pumping stations developed to date.

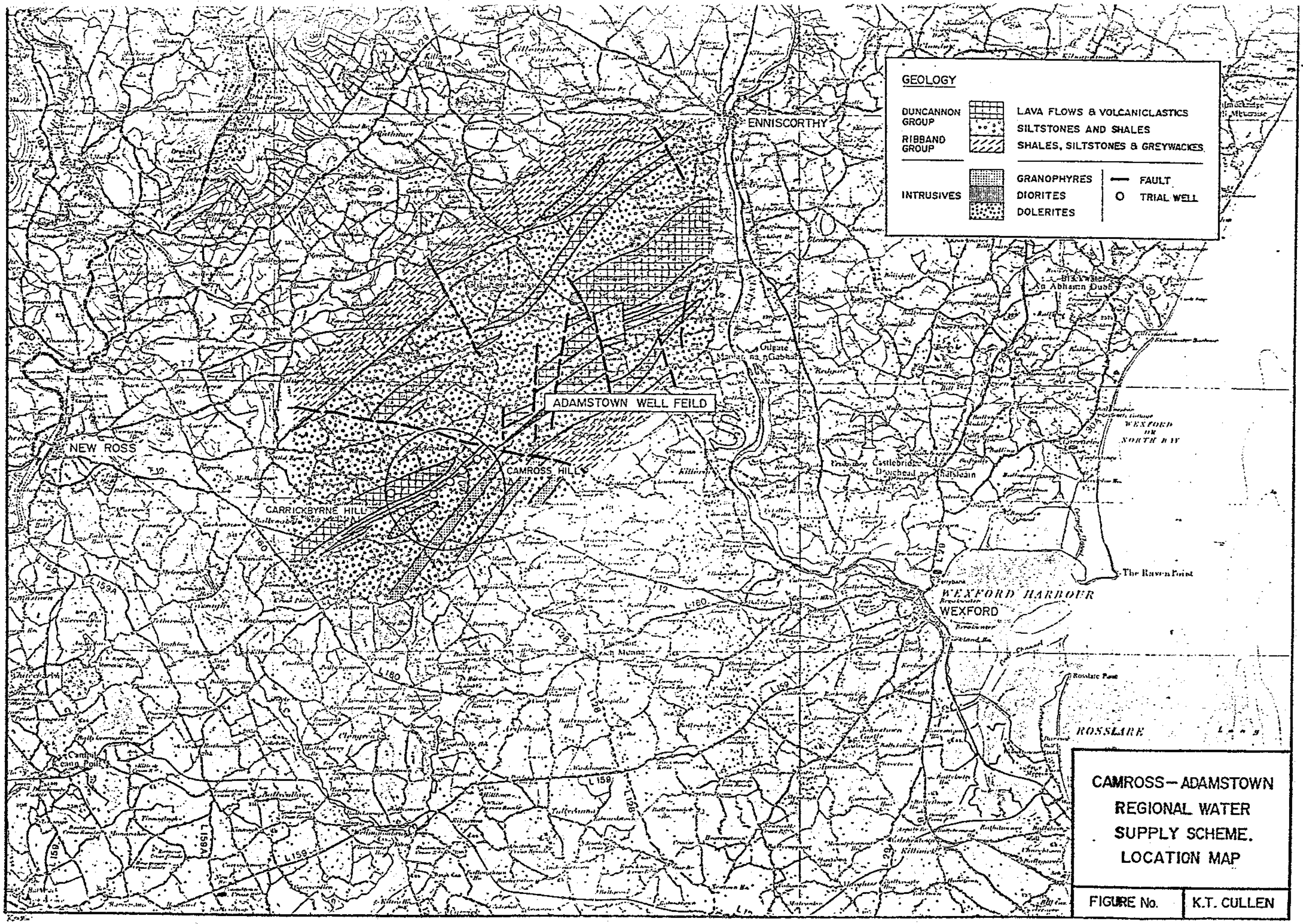
The location, geological setting and construction details of the trial wells at Adamstown are given on the accompanying drawings and table.

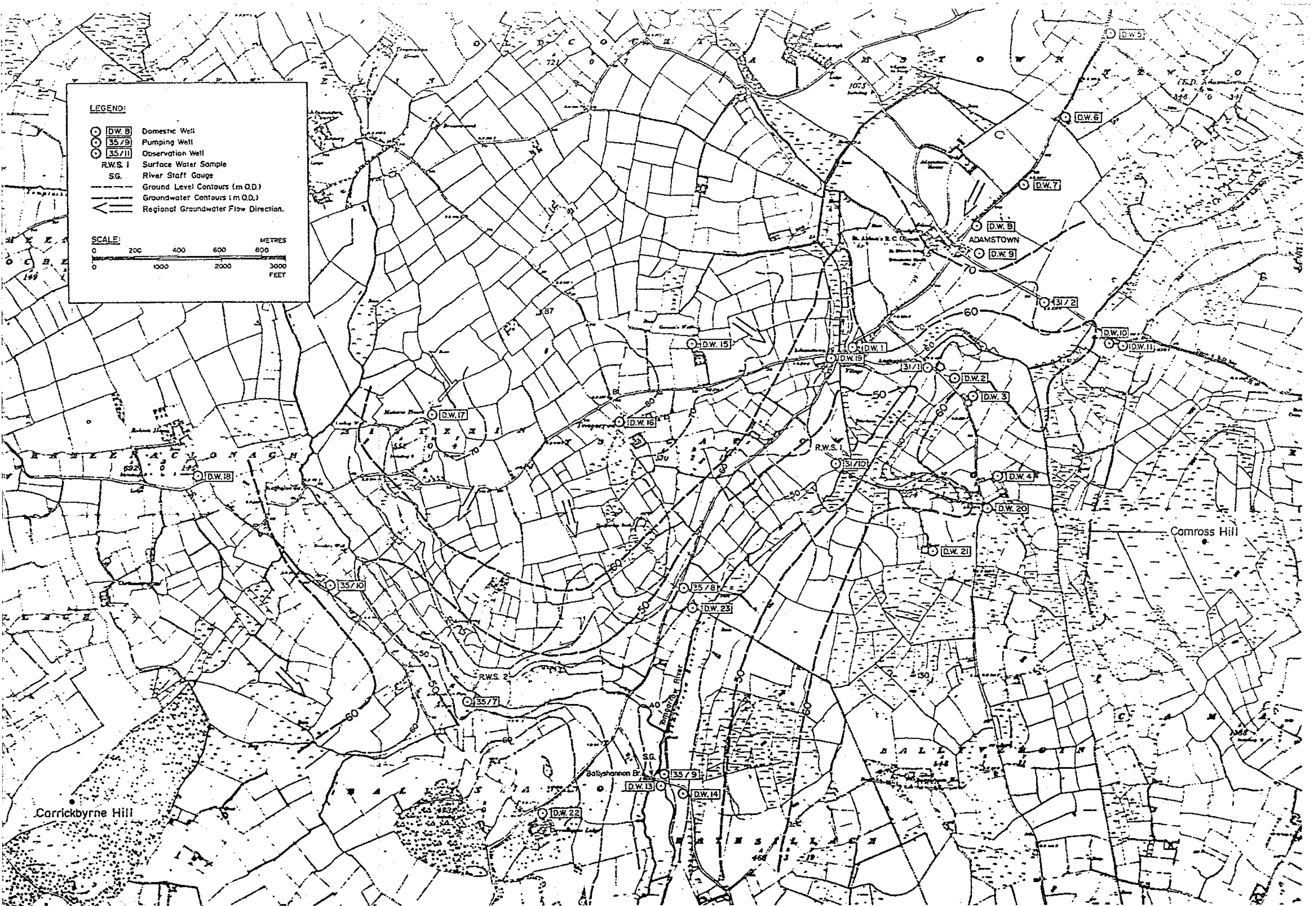
Short duration pumping tests were carried out on Well No's 31-10 and 35-7 to provide some basic information on the potential of these wells. Both wells proved very productive and each was capable of yields in the order of 2,000 m3/day. Well No. 35-7 provided the best specific capacity value to date of 216 m3/day/m. Well No's 35-8 & 9 remain to be test pumped.

A 9 - day pumping test was carried out on trial wells 31-1, 31-10 and 35-7. The start of the test was staggered to determine the effect of each pumping well on the observation wells. However, a rising water table due to intense rainfall at the start of the test limited the value of the time-drawdown data from the monitoring wells. However, it was possible to pump the three wells at a combined output of 4545 m3/day (1 m.g.d.) for the last 7 days of the test. This result confirms the overall potential of the volcanic aquifer at Adamstown and provides a minimum yield for the proposed well field of 1 m.g.d.. This figure can be compared with the total annual rainfall for the surface water catchment of 50,000 m3/day (11 m.g.d.) which should provide sufficient recharge to meet the long-term projected demand on the scheme of 9,000 - 13,600 m3/day (2 - 3 m.g.d.).

The groundwater from the Adamstown well field is of good chemical and bacteriological quality and is characterised by a low T.D.S. value of 200 mg/l and a hardness of less that 150 mg/l as CaCO3. The sample from Well No. 31-10 was anomalous with a positive bacteriological result and high levels of iron and manganese. A survey of all domestic wells in the area will be undertaken to investigate the extent of this variation in groundwater quality.

The author wishes to thank Wexford County Council for permission to present this paper.


GEOLOGY
DUNCANNON GROUP
LAVA FLOWS & VOLCANICLASTICS
SILTSTONES AND SHALES
RIBBAND GROUP
SHALES, SILTSTONES & GREYWACKES
INTRUSIVES
GRANOPHYRES
DIORITES
DOLERITES
FAULT
TRIAL WELL
ENNISCORTHY
ADAMSTOWN WELL FEILD
NEW ROSS
CAMROSS HILL
CARRICKBYRNE HILL
WEXFORD HARBOUR
WEXFORD
WEXFORD OR NORTH BAY
ROSSLARE
The Raven Point
L160
L128
L159
L159A
CAMROSS—ADAMSTOWN REGIONAL WATER SUPPLY SCHEME. LOCATION MAP
FIGURE No.
K.T. CULLEN



LEGEND:
D.W. 8 Domestic Well
35/9 Pumping Well
35/11 Observation Well
R.W.S. 1 Surface Water Sample
S.G. River Staff Gauge
Ground Level Contours (m O.D.)
Groundwater Contours (m O.D.)
Regional Groundwater Flow Direction.
SCALE:
METRES
0 200 400 600 800
0 1000 2000 3000
FEET
ADAMSTOWN
Camross Hill
Carrickbyrne Hill
Ballyshannon Br.
Tomgarrow River
D.W. 1
D.W. 2
D.W. 3
D.W. 4
D.W. 5
D.W. 6
D.W. 7
D.W. 8
D.W. 9
D.W. 10
D.W. 11
D.W. 13
D.W. 14
D.W. 15
D.W. 16
D.W. 17
D.W. 18
D.W. 19
D.W. 20
D.W. 21
D.W. 22
D.W. 23
31/1
31/2
31/10
35/7
35/8
35/9
35/10
R.W.S. 1
R.W.S. 2
S.G.
70
60
50
40

Well No.	Depth (m)	Casing (m)	Diameter (m.m.)	Drilling Date	Static Water level (m)	Pumping Rate m.3/day	Specific Capacity m3/d/m.
31-1	61.0	9.0	200	Oct '79	3.36	620	30
31-2	61.0	10.0	200	Nov '80	8.95	1,400	45
31-10	54.80	10.00	200	Oct '86	3.09	2,000	122
35-7	48.7	1.0	225	Oct '86	4.03	2,000	216
35-8	46.5	5.0	225	Nov '86	8.95	1,600 (E)	-
35-9	62.0	9.0	225	Nov '86	Flowing	550 (E)	-
35-10	?	?	200	June '82	5.15	2,000	-

E = Estimated: Water Levels measured below ground level

Table 1: Construction Details of Co. Council Wells at Adamstown, Co. Wexford.

OVERSEAS CONSULTANCY WORK FOR IRISH HYDROGEOLOGISTS

by

David J. Burdon

Resume of an introductory talk at IAH Meeting, Portlaoise, 7-8 April, 1987.

This is a brief resume of the favourable and unfavourable aspects for Irish hydrogeologists working overseas as consultants. It does not deal with overseas drilling contracts, nor with costs, organizational aspects, health or other non-technical matters.

1. Openings - Areas and Subjects

The main areas of such hydrogeological consultancy work lie in the arid and semi-arid zones of the world. Many of the countries in these zones are backward and under-developed, mainly due to shortage of water. Many of them are poor; some were oil-rich, but with falling oil prices and so income, they tend not to spend money on groundwater investigations, development and management. In countries with higher precipitation, there have been problems concerning groundwater development. These include over-extraction, coastal sea-water intrusion, aquifers with saline groundwater and other specialized hydrogeological problems. More recently, the problem of groundwater pollution has become of major importance, broadening into the overall protection of the environment. It could be that Irish hydrogeologists are in the forefront of dealing with the problems of protection of groundwater from agricultural pollution.

2. Sources of Project

Most international projects dealing entirely, but more usually in part, with groundwater arise from various types of technical assistance to less-developed countries. In this the UN itself and many of its specialized agencies (UNesco, FAO, WMO, IAEA, etc.) have played a major role with much emphasis on groundwater. Again the

World Bank often funds and operates projects with large groundwater components; thus the well-known Irish hydrogeologist, Mike Barber has done much work for the World Bank in India. The EEC, as under the Lome Agreement, have also funded projects, but few of these seem to be in the groundwater fields. When groundwater projects are funded under bilateral arrangements, the donor country expects its own nationals to be employed. The Irish contribution to Lesotho has given rise to a limited amount of groundwater consultancy work; there has also been some groundwater development for stock watering in Sudan.

GORTA has emphasised the importance of water in direct and anti-famine operations and in the long-term development and use of groundwater. This was much stressed at the GORTA seminar "Water and the Third World" in Dublin in October, 1984. Irish Embassies abroad should notify our Government of proposals for water projects; it might be advisable for the Irish Group of the IAH to make formal liaison with the Department of Foreign Affairs on this matter.

3. Irish Position

Documentation for this seminar includes a paper entitled "Irish Contributions to International Hydrogeology". It summarises the rapid rise of Ireland from almost no hydrogeology in around 1970 to a prominent place in international hydrogeology in 1987. A glance at this paper will show the wide range of hydrogeological disciplines to which the Irish hydrogeologists are making substantial contributions.

Attention may be drawn to one discipline - the interactions between farming and agriculture with the pollution of groundwater. The paper "Impact of Agriculture on Groundwater in Ireland" was read at the XVI Congress of the IAH in Prague in 1982. It has been published not only in the Memoires of that Congress, but also in Vol.V of "Environmental Geology" in 1983 and in a special publication of the IAH in 1986/7. The fact that six papers read at the 1984 Irish groundwater meeting were selected and published in a special number of "Environmental Geology" Vol.IX in 1986 also shows how interested the international hydrogeological and environmentalists are in these aspects of Irish research.

Another specialized field in which the Irish are making great progress is the application of the hydrogeological input to arterial and farm drainage. However, in the arid and semi-arid regions, drainage of irrigated lands emphasis the removal of precipitated salts (mainly sodium) with the drainage water; this differs greatly from the Irish experience.

4. Specialization

In many of the disciplines of hydrogeology, the Irish are making notable progress. Hydrogeothermal investigations, with some EEC-support, have made much progress over the past seven years. Development is now in progress in Mallow. There have been numerous Irish contributions to the scientific Commissions of the IAH, in particular to the Karst and Volcanic Rocks and Agricultural Commissions. There have been many investigations as to the hydrology and hydrogeology of peat, leading to some consultancy work in Senegal by Wright. There has been specialized research on the temperatures of groundwater and the effect of earth tides on groundwater; these are unlikely to lead to consultancy work.

But the outstanding and most successful specialization has been on dangers and avoidance of pollution from farming activities. These include inorganic pollution, as from nitrogen, and organic pollution, as from silage. The subject readily expands into protection of the environment, a matter which is of grave and urgent importance today. This would seem to be the specialization in which Irish hydrogeologists should merit a place on all international teams investigating the environment in countries where agriculture plays a dominant or appreciable part of the life of each region or country.

5. Favourable Factors

Irish hydrogeologists are well-known from their publications and contacts and have obtained a high standing in international circles. The Irish are free of involvement with international and national power politics; they are always politically acceptable. The Irish outlook fits in well with the outlook of most developing countries; they cooperate naturally and well with local scientists and technicians. Compared with USA personnel, Irish salaries are low; compared with say Hungary or Yugoslavia, Irish salaries are high.

6. Unfavourable Factors

Currently, there are several factors which are unfavourable to Irish hydrogeologists obtaining consultancies abroad. These are all outside the control of the Irish hydrogeologist. The once-rich oil-producing countries lie mainly in the arid and semi-arid regions; when rich, they spend freely on the investigation and development of their groundwater resources. With falling incomes, the amounts of money available for hydrogeological investigations has sharply declined and so has the employment of international consultants. Most developing countries have had their own nationals trained in all branches of science, including hydrology, hydrogeology, geophysics and associated subjects used in hydrogeology. This training has taken place over the past 35 years, and there are now good, and often very good and experienced, national hydrogeologists, so that outside staff and even high-level advice are no longer necessary. See what Ireland has done on hydrogeology over the past 20 years.

The Irish hydrogeological experience has been gained mostly under humid conditions; it calls for quite a change of approach to practice hydrogeology under arid or semi-arid conditions, though this difficulty is readily overcome. Again, Ireland's groundwaters are not over-developed or over-pumped; over-development and the need for artificial recharge of all forms are problems of the arid regions on which no experience can be gained in Ireland.

IRISH CONTRIBUTIONS TO INTERNATIONAL HYDROGEOLOGY

by

David J. Burdon

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I BACKGROUND TO THE DEVELOPMENT OF KNOWLEDGE OF HYDROGEOLOGY IN IRELAND AND ITS INTERACTION ABROAD

II HYDROGEOLOGICAL MAP OF EUROPE AND EXPLANATORY NOTES

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IV CONGRESSES OF THE INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IAH)

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VI HYDROGEOTHERMAL MEETINGS AND PUBLICATIONS

VII PAPERS AND PUBLICATIONS TO INTERNATIONAL ORGANIZATIONS AND MEETINGS

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IX POST-GRADUATE RESEARCH ON HYDROGEOLOGY IN IRELAND AND ABROAD

X REPORTS DEALING WITH EEC AND ALLIED SUPPORT TO FOREIGN GOVERNMENTS

XI MISCELLANEOUS

XII REFERENCES
- XII-1 Main List of Publications, Papers and Reports
- XII-2 First Irish International Hydrogeological Meeting, May, 1979
- XII-3 Second Irish International Hydrogeological Meeting, June, 1984

A paper for the Port Laoise Meeting
of the Irish Group of the IAH, on
7-8 April, 1987

16 February, 1987.

IRISH CONTRIBUTIONS TO INTERNATIONAL HYDROGEOLOGY

by

David J. Burdon

This paper attempts to cover all the main contributions of Irish hydrogeologists to the progress of hydrogeology throughout the world. Section I summarises the early history of Hydrogeology in Ireland. Since the Irish Group of the International Association of Hydrogeologists (IAH) was founded only in 1975, there is little on pure hydrogeology before that date. There are, however, very many studies and publications before that date on drainage and allied agricultural waters which though not by hydrogeologist, do deal with aspects of hydrogeology; a few of these, as by Dooge and O'Lean are noted briefly here.

The major item of the paper is the references - bibliography with which it ends. This includes separate references for the two main hydrogeological meetings held in Ireland by the Irish Group of the IAH in 1979 and 1984. Their proceedings were published by the Irish National Committee for UNesco's International Hydrological Programme. Within the text, authors and date of paper are given; the full titles are given only in the bibliography. This helps to keep the main text reasonably short.

It is probable that there are some omissions. These are regrets by the author, and his apologies are made to any who have contributed to international hydrogeology and are omitted here.

I - BACKGROUND TO THE DEVELOPMENT OF KNOWLEDGE OF HYDROGEOLOGY IN IRELAND AND ITS INTERACTION ABROAD

The first contact by an Irish official with international scientific groundwater development was by John O'Loan, the Senior Inspector in the Department of Agriculture in charge of farm buildings and farm water supplies. In the course of a study course in the USA in the mid 1950's he visited the Geological Survey of Illinois. He was so impressed by what he saw of their hydrogeological support to farmers that he became convinced that groundwater had a major role to play in providing water supplies for Irish farmers if it could be developed with proper scientific guidance.

O'Loan used the opportunities provided in the early 1960's by his membership of the Interdepartmental Committee on Water Resources and then from 1964 as a member of the Irish National Committee of the UNesco sponsored International Hydrological Decade, to try and promote the cause of groundwater in Ireland.

In 1966 the Irish IHD Committee were requested by UNesco to provide data on all aspects of hydrology in Ireland. Aldwell was asked as the GSI representative on the Committee to do a chapter on groundwater in Ireland. To study how best to proceed, Aldwell was sent by the Committee to visit the British Geological Survey in Belfast and London in 1967. He was received with every courtesy and was much struck by the enthusiam evident in London by the members of the newly formed Groundwater Section under Buchan and Gray. They made suggestions on how best to begin to organise things in Ireland.

At this time the only other work being done in Ireland relating to hydrogeology was on karst. Teams working under Tratman from Bristol University had been working in Clare for many years and in 1969 their book on the caves of NW Clare was published, Tratman (1969). Meantime in the Geography Department in T.C.D. Paul Williams was doing work on Irish Karst, as Williams (1966, (1970) and (1973). In 1970 he gave a talk on groundwater management in Ireland and this appeared as a short paper in the QJEG (Vol.4, pp.334-335) in 1971 as The Management of Groundwater Resources in the Republic of Ireland.

The first official input to an international hydrogeological project by Ireland started in February 1969 when Aldwell was sent by the GSI as the Irish representative to the UNesco/IAH project 'The International Hydrogeological Map of Europe'. This involved regular meetings in UNesco, Paris and the German Geological Survey in Hannover. It also required liaison with the Belgian, British and French and Northern Ireland Geological Surveys for sheet B4. The maps and explanatory notes were published in 1978 to 1980.

Back in Ireland in 1971 a IHD Groundwater sub-Committee comprising of P. O'Kane and Aldwell published a report 'Groundwater Use in Ireland Today' in An Foras Forbartha. Also in 1971 E.P. Daly was recruited to the GSI, having done his masters degree in North Carolina State Unviersity with support from the U.S. National Committee of the IHD.

About 1972 at a meeting of the European Hydrogeological Map Committee in Paris, C.R. Aldwell was invited to join the IAH by S. Buchan and L. Dubertret and thus became the first resident Irish member of IAH.

This Section I is based on material kindly supplied to the author, by his colleague Mr C.R. Aldwell, of the Geological Survey of Ireland.

II - HYDROGEOLOGICAL MAP OF EUROPE & EXPLANATORY NOTES

This was basically drawn-up by the Mapping Commission of IAH under Professor H. Karrenberg, with support from UNesco and others. Sheet B.4 (London) was published in 1978, and covers the south of Ireland. The authors were C.R. Aldwell, J.B.W. Day and W. Struckmeir for the Report; E.P. Daly helped with the Map. Several detailed sections on Ireland are by Aldwell, as Items 2.3, 3.2 and 4.2.. Sheet B.3 (Edinburgh) was published in 1980, and extends into Donegal and some adjacent areas of the Republic; it covers most of Ulster. For the explanatory Report the authors are J.R.P. Bennett and I.B. Harrison. Sections of it deal in some detail with the northern portion of Ireland; Aldwell & E.P. Daly helped with drafting the map.

III - HYDROGEOLOGICAL MEETINGS IN IRELAND

In July, 1978, the European Association of Exploratory Geophysics held a meeting in Ireland; Eugene Daly led them on a field-trip dealing with the hydrogeology of the Nore Basin.

From 22 to 27 May, 1979, the Irish Group of the IAH hosted a large meeting on the "Hydrogeology of Ireland". At the main scientific meeting at TCD on 25 May, 9 papers were presented and discussed, by Dr. Williams, Aldwell and Burdon, Bennett, Wright, E.P. Daly, Drew, Hartwell, Jordan & Gutmanis, D. Daly and Cullen. Titles will be found in the Bibliography dealing with this meeting. There was a field trip on 22-23 May for the Karst Commission of the IAH; these included a field guide to the Burren by Drew and Plunkett-Dillon, as well as some comments on Irish karst by Burger, Bono, LeGrand and Zotl, chairman and members of the Karst Commission. After the scientic meeting, there was a field-trip on 26-27 May, for which field guides were prepared by E.P. Daly and G.R. Wright.

From 12 to 15 June, 1984, the Irish Group of the IAH in co-operation with An Foras Taluntais, hosted a large meeting on the "Impact of Agriculture on Groundwater in Ireland". This meeting was primarily to give the IAH Working Group (now a Commission) "The Impact of Agriculture in Groundwater" a chance to study at first-hand the Irish position. Scientific papers were presented by Aldwell, Lee, Toner, Sherwood and D. Daly at Johnstown Castle, by O'Kiely, Wright and Tunny at Moorepark and by Ryan, Burdon and Mulqueen at Creagh, Ballinrobe. There was also a field-trip to limestone areas in Cos. Clare and Galway, for which Drew prepared a field guide. Titles for the papers presented will be found under a separate sub-heading in the Bibliography.

In October, 1984, GORTA held a seminar in Dublin on "Water and the Third World". At it, papers were presented by Dooge, Reynolds, Burdon, and Nash, dealing essentially with water and groundwater; some other papers were of a more general nature. These water papers are noted in the general alphebetically-ordered Bibliography.

IV - CONGRESSES OF THE INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IAH)

Irish hydrogeologists have presented papers to four Congresses of the IAH, Birmingham, England in 1977; Prague Czechoslovakia in 1982; Cambridge, England in 1985; and Karlovy Vary, Czechoslovakia in 1986. Plans are well advanced to present papers on Irish hydrogeology to the XX Congress of IAH in Rome, East 1987, and to the XXI Congress of the IAH in China in October, 1988.

At Birmingham, a paper was presented by Aldwell et al (1977), and there were many contributions to the discussion, in particular on the training of hydrogeologists, as by the US Geological Survey. At Prague, there was a paper by Aldwell, Burdon and Sherwood, which was published not only in the proceeding of that meeting, but also in Environmental Geology in 1983, Vol.5, pp.39-48. There was also a paper on nitrates by E.P. Daly and D. Daly, (1982).

At Cambridge in 1985, Aldwell, Burdon & Peel presented a paper "Heat Extraction from Irish Groundwaters" and Burdon on "Groundwater against Drought in Africa". At the Karlovy Vary Congress, Aldwell & Burdon presented a paper (1986) "Aspects of Groundwater and Land Use in Ireland". Dr. David J. Burdon was made an Honorary Member of the International Association of Hydrogeologists at this Karlovy Vary Congress, an honour for Ireland.

Burdon (1987) will present "Energy from Groundwater" to the XX IAH Congress in Rome at Easter, 1987.

V - WORK ON THE COMMISSIONS OF IAH

Irish hydrogeologists have been active on many of the Nine Commissions which carry out the basic scientific work of the IAH. Their work on the Hydrogeological Maps Commission has already been noted.

The Hydrogeology of Karst Commission arose from a Working Group on the Hydrology of the Carbonate Rocks of the Mediterranean, operated by FAO and UNesco, of which Dr. Burdon was the technical secretary. So, he was a founder member of the Karst Commission. In 1985, he contributed "Second Volume of the Annotated Bibliography of Carbonate Rocks", giving some 111 entries covering Ireland. With David Drew of TCD, (1986), he has submitted a long paper "Hydrogeology of Selected Areas of the Karst of Ireland" for inclusion in a forthcoming publication by the Karst Commission. David Drew's "The Effect of Human Activity on a Lowland Karst" has been published in 1984 by the Karst Commission's "Hydrogeology of Karstic Terrains - Case Histories".

The Commission on the Hydrogeology of Volcanic Terrains has been slow to publish, but a major work is expected in 1987. Burdon & Cullen had an early contribution (1980) which was read at Catania, Sicily. In 1986, there were three Irish contributions; two by Burdon on Ordovician Volcanics in Co. Wexford and Dinantian Volcanics in Co. Limerick, and one by Bennett on the Tertiary Basalts of the North. In addition, Burdon contributed from his work on volcanics in South Korea, Syria-Jordan and Cyprus.

On the Commission for Groundwater Protection, C.R. Aldwell has played a major role, mainly with inter-relationships of Irish Agriculture with groundwater. This included attendance at meeting, planning the organization and work of these Commissions, at London 1980, at Noordwijkerhout, Netherlands (March, 1981), Hannover, Lower Saxony (March, 1983), and Denmark 1986 as well as arranging the 1984 visit of the Commission to Ireland.

VI- HYDROGEOTHERMAL MEETINGS AND PUBLICATIONS

EEC financial support for the investigation of the geothermal potential gave a strong impetus to such investigations, with emphasis on warm, tepid and cold groundwaters from which energy could be extracted. Ireland had no contribution to the EEC meetings of Geothermal in Brussels in 1977 and in Strasbourg in 1980. The first

Irish contribution to geothermal energy was a paper "Hydrogeothermal Conditions in Ireland" read by Aldwell & Burdon at the XXVI International Geological Congress in Paris in 1980. However, by the EEC meeting on "European Geothermal Update" in Munich in 1983, there were four papers from Ireland - Aldwell on the general position, and Burdon et al, Brock et al and Bruck et al on specific areas and aspects of Irish geothermal. In addition, Aldwell took part in several meetings on geothermal energy development in Europe, as Florence, Italy (May 1982), and Orleans, France, (Nov., 1982).

VI - PAPERS AND PUBLICATIONS TO INTERNATIONAL ORGANIZATIONS AND MEETINGS

Here are listed papers read at other international meetings and publications by Irish hydrogeologists made by UNesco, UN, New York and others. Since the full titles of these publications are given in the Bibliography, only authors names and location are listed here.

1. Burdon, D.J. (1975); Kentucky
2. Aldwell, C.R. & Wright, G.R. (1978); Malta
3. Wright, G.R., Aldwell, C.R., Daly, D. & Daly, E.P. (1982); EEC
4. Wright, G.R., Daly, D. & Daly, E.P. (1983); EEC
5. Burdon, D.J. (1984); UNesco, Paris
6. Aldwell, C.R. (1984); Inter. Geol. Congress, Moscow
7. Aldwell, C.R. & Burdon, D.J. (1986); Budapest
8. Burdon, D.J. (1985); Fogarra, TCD, Dublin
9. Burdon, D.J. (1985); Taormina, Sicily
10. McCumiskey, L.M. (1986); Eng. Group, Third World Devel.
11. Burdon, D.J. (1987); Florida Sinkhole Research, USA
12. Burdon, D.J. (in press); United Nations, New York.

VII - PUBLICATIONS IN INTERNATIONAL JOURNALS

Here are listed papers published in international journals and related types of publication by Irish scientists and hydrogeologists. The papers published before 1977 and some later are by hydrologists and agriculturists dealing directly or indirectly with groundwater, as in the drainage of bogs and fens. After 1977, papers by hydrogeologists appear, though it will be noted that Irish hydrogeologists tend to publish with the IAH and at technical meetings rather than in international journals. As noted for the preceeding Section, only authors names and location are listed here, since the full titles of the publications are given in the Bibliography.

1. Gorham, E. (1957); Royal Irish Academy (RIA)

2. Dooge, J. (1959), Jour. Geophy. Research

3. Williams, P.M. (1966); Inst. of British Geog.

4. Williams, P.M. (1970); Irish Geog. Studies, Queens, Belfast

5. Dooge, J. (1972); Minsk Sym; UNesco

6. Dooge, J. & Keane, R. (1972); minsk Sym., UNesco

7. Bowen R. & Williams, P.M. (1972); Experientia

8. Burke, W. (1972); Minsk Sym., UNesco

9. Bowen, R. & Williams, P.M. (1973); Water Resources Research

10. Drew, D. (1973,a). Proc. 6th Inter. Speleology Congress

11. Drew, D. (1973,b). Irish Geog., Vol.6

12. Mulqueen, J. (1975); Inter. Symp. on Peat in Agriculture

13. Mulqueen, J. & Harrington, D. (1976); Physics in Industry, Pergamon press

14. Mulqueen, J. & Gleeson, T.N. (1981); Research on Land Use, Cambridge

15. Burdon, D.J. (1978); Royal Soc., London

16. Daly, D., Lloyd, J.W., Misstear, D.R. & Daly, E.P. (1980); QJEG, London.

17. Lynn, M.A. (1982); Irish Nat. Committee for IHP

18. An Foras Forbartha (1983); Water Pollution Advisory Council

19. Aldwell, C.r. & Burdon, D.J. (1986) QJEG, London

20. Burdon, D.J. (1986); Environmental Geology

21. Bruck, P.M., Cooper, C.E., Duggan, K., Goold, L. & Wright, D.J. (1986); Jour. Earth Sci., RDS, Dublin.

IX - POST-GRADUATE RESEARCH ON HYDROGEOLOGY IN IRELAND AND ABROAD

Post-graduate studies, mainly leading to the M.Sc. degree in hydrogeology, are an important means of bringing Irish hydrogeological conditions into the much wider scope of world hydrogeology. Of this, there are two aspects. The first is when post-graduate students from abroad study Irish hydrology and hydrogeology; graduates of the Free University of Amsterdam are outstanding in this respect. The other aspects is when Irish graduates study abroad, often with their theses on Irish subjects; work at Birmingham University and at universities in the USA is the most important. Queen's Belfast must also be noted, Walker (1963) & (1968).

From the Free University of Amsterdam there are Von Ree & Rot (1981) and Kempers (1981), both working in the basin of the Cork Blackwater. There are also De Wit (1979), Van Patten (1978), de Buissonje (1977) and Ankers (1978).

From Birmingham, there are Kevin Cullen and Donald Daly, while Eugene Daly is working on a Ph.D. thesis there also. From the USA, there are Eugene Daly (1974), Breda Naughton (1978) and Bridgit Scanlon (1983). Other Irish hydrogeologists who submitted such theses are David Ball.

Theses to UCD, UCC, UCG & TCD are not considered "International" and so are not listed here.

X - REPORTS DEALING WITH EEC AND ALLIED SUPPORTS TO FOREIGN GOVERNMENTS

Offers to carry out hydrogeological work for foreign governments have been made, in many cases involving the backing of the EEC in Brussels, or other agencies which support such work. Some of these have been executed, as in Egypt, Lesotho and Greece; but many others are pending, due mainly to the drying-up of funds in one-time oil-rich countries located in the arid or semi-arid regions of the world.

Only a selected few are noted here. Wright worked on peat in Senegal and groundwater in Eritrea. Burdon reported (1984) to Syria, for Ain Figeh and the South-West of the Alaween Mountains; Burdon (1984) and Peel (1984) for Lesotho town water supplies; Burdon (April, 1985) for the Mpongwe Block, Zambia and Burdon (May, 1985) for RTE on Egypt and Libya. The work in Egypt was of a major nature, funded in part by the UNDP; it covered the years 1980-83, and resulted in a major report "Regional Development Planning Region 8 - Arab Republic of Egypt -Volume 3: Water Resources". The work was undertaken under the overall consultancy of Dar Al-Handasah, but the water work was all by Burdon and Peel, under whose name this work is listed in the Bibliography.

XI - MISCELLANEOUS

Happily, there are very few papers, publications or reports on Irish hydrogeology in the international spheres which are not covered by the preceeding ten headings. At present the only one noted is Aldwell (March, 1983), to the International Commission on Irrigation and drainage.

It is also of interest to note that on 13 March, 1982, the Institution of Geologists awarded their Aberconway Medal to Dr. David J. Burdon for outstanding work in the broad fields of hydrogeology throughout the world.

XII - REFERENCES

This is the longest portion of this paper, and gives details of all publications, papers and reports by Irish hydrogeologists and others designed to reach other hydrogeologists all over the world.

Part X-1 is the main list, arranged first in alphabetical and then in chronological order. Parts X-2 and X-3 list the papers presented, the field guides and related matters of the First Irish International Hydrogeological Meeting in May, 1979 and the Second Irish International Hydrogeological Meeting in June, 1984.

XII-1 Main List of Publications, Papers and Reports

Aldwell, C.R. (March, 1981) "International Symposium on the Quality of Groundwater" Noordwijkerhout, Netherlands.

Aldwell, C.R. (28 March, 1981) Third Meeting of the IAH Working Group "The Influence of Agriculture on Groundwater" Noordwijkerhout, Netherlands.

Aldwell, C.R. (May, 1982) "International Geothermal Energy Conference" Florence, Italy.

Aldwell, C.R. (Nov., 1982) "Groundwater as a Conveyor of Energy" and "Les Milieux Discontinus en Hydrogeologie" Symposium at BRGM, Orleans, France.

Aldwell, C.R. (March, 1983) Meeting of IAH Working Group "Impact of Agricultural Activities on Agriculture" Hannover, Lower Saxony.

Aldwell, C.R. (1983) "Review of Geothermal Investigations and Potential Development in Ireland" EEC "European Geothermal Update" Munich.

Aldwell, C.R. (August, 1984) "XXVII International Geological Congress", Moscow, USSR.

Aldwell, C.R. and O'Kane, P. (1971) "Groundwater Use in Ireland Today" An Foras Forbartha.

Aldwell, C.R., Daly, E.P., Ede, E.P., Burdon, D.J. & Wright, G.R. (1977) "Overcoming Obstacles to Groundwater Development in the Republic of Ireland" IAH Mem. Vol.XIII, Birmingham, England.

Aldwell, C.R. & Wright, G.R. (1978) "Groundwater in Coastal Areas of Ireland (Republic)" UN Economic Commission for Europe "Selected Water Problems in Island and Coastal Areas" Malta.

Aldwell, C.R. & Daly, E.P. (1978) Map B.4, Republic of Ireland Portion Map.

Aldwell, C.R., Day, J.B. & Struckmeier, W. (1978) "Explanatory Notes for the International Hydrogeological Map of Europe - Sheet B.4, UNesco, Paris.

Aldwell, C.R. & Burdon, D.J. (1980) "Hydrogeothermal Conditions in Ireland" XXVI Inter, Geol. Congress, Paris; Fossil Fuels Sec. 14.2;14.0068:21.

Aldwell, C.R. & Daly, E.P. (1980) Map B-3 - Republic of Ireland Portion of Map.

Aldwell, C.R., Burdon, D.J. & Sherwood (1982) "Impact of Agriculture on Groundwater in Ireland" IAH Mem. Vol.XVI, Congress of Prague, Czechoslovakia, pp.99-114.

Aldwell, C.R., Burdon, D.J. & Sherwood, M. (1983) "Impact of Agriculture on Groundwater in Ireland" Environmental Geology, Vol.V, pp.39-48.

Aldwell, C.R. & Burdon, D.J. (1985) "Energy Extraction from Irish Groundwaters" JIGA Meeting in Bordeau, France.

Aldwell, C.R., Burdon, D.J. & Peel, S. (1985) "Heat Extraction from Irish Groundwaters" IAH Mem. Vol.XVIII, Congress of Cambridge, England, pp.79-94.

Aldwell, C.R. & Burdon, D.J. (1986) "Energy Potential of Irish Groundwater" QJEG, Vol.19, pp.133-141.

Aldwell, C.R. & Burdon, D.J. (July, 1986) "Temperature of Infiltration and Groundwater" International Association of Hydrological Science, Budapest, Hungary.

Aldwell, C.R. & Burdon, D.J. (1986) "Aspects of Groundwater and Land Use in Ireland". IAH Mem. Vol.XIX, Congress of Karlovy Vary, Czechoslovakia.

Aucker, H. (1978) "A Reconnaissance Survey of the Groundwater around Mallow, Co. Cork, and Some Remarks on the Mallow Warm Springs" Thesis, Free Univ. Amsterdam.

An Foras Forbartha (June, 1983) "A Review of Water Pollution in Ireland" A report to the Water Pollution Advisory Council, p.152.

Ball, D. (1972) "A Short Field and Desk Study of the Hydrogeology of the Kings River Catchment, Ireland" M.Sc. Thesis, Univ. College, London.

Bennett, J.R.P. & Harrison, I.B. (1980) Explanatory Notes for the International Hydrogeological Map of Europe - Sheet B.3, UNesco, Paris.

Bennett, J.R.P. (1987) "Tertiary Antrim Basalts" Contribution to the IAH Commission on the "Hydrogeology of Volcanic Terrains".

Bowen, R. & Williams, P.W. (1972) "Tritium Analyses of Groundwater from the Gort Lowlands of Western Ireland" Experientia, Vol.28, (Verlag, Basel), pp.497-498.

Bowen, R. & Williams, P.W. (1973) "Geohydrologic Study of the Gort Lowlands and Adjacent Areas of Western Ireland, using Environmental Isotopes" Water Resources Research, Vol.9, pp.753-758.

Brock, A. & Barton, K.J. (1983) "Equilibrium Temperature and Heat Flow Density Measurements in Ireland" EEC "European Geothermal Update" Munich.

Bruck, P.M., Cooper, C.E., Duggan, K., Gould, L. & Wright, D.J. (1983) "Geochemistry and Geothermal Potential of the Warm Springs of Munster, Ireland" EEC "European Geothermal Update" Munich.

Bruck, P.M., Cooper, C.E., Duggan, K., Gould, L. & Wright, D.J. (1986) "The Geology and Geochemistry of the Warm Springs of Munster" Jour. Earth Sci., RDS, Vol.7, pp.169-194.

Burdon, D.J. (1976) "Influence of Karst on Engineering in Ireland" Meeting on "Hydrologic Problems in Karst Regions" Western Kentucky University, USA.

Burdon, D.J. (1978) "Contribution to discussion on "Effects of the 1975-76 Drought on Groundwater and Aquifers" in "Scientific Aspects of the 1975-76 Drought": Royal Soc., London, pp.66-67.

Burdon, J. (April, 1984) "Possible Development of Groundwater in Lesotho".

Burdon, D.J. (1984) "Full Development and Use of the Waters of Ain Figeh and the Barada Valley, Syrian Arab Republic" Proposals to the EEC for technical assistance to Syria.

Burdon, D.J. (1984) "Underground Storage and Retrieval of Winter Runoff Waters of the South-West Region of the Alaween Mountains, Syrian Arab Republic" Proposals to the EEC for technical assistance to Syria.

Burdon, D.J. (1984) "Groundwater Can Mitigate Drought" GORTA, Dublin, 16 Oct., 1984. Seminar "Water and the Third World".

Burdon, D.J. (1984) "Methods of Cost Estimation" in "Guide to the Hydrology of Carbonate Rocks" UNesco, Paris.

Burdon, D.J. (1985) "Groundwater Against Drought in Africa" IAH Mem. Vol.XVIII, Congress of Cambridge, England, pp.76-91.

Burdon, D.J. (1985) "Contribution to the proposed Second Volume of the "Annotated Bibliography of Carbonate Rocks" - 111 entries covering Ireland. To the Karst Commission of IAH.

Burdon, D.J. (April, 1985) "Outline Proposals for an Hydrogeological Study of the Mpongwe Block, Copperbelt Province, Republic of Zambia".

Burdon, D.J. (May, 1985) "Waters of Egypt and Libya" Notes for an interview with Mr Gerry O'Callaghan of RTE on 9 May, 1985.

Burdon, D.J. (1985) "The Fogarra" "Case Studies in Technology Transfer" TCD, 26 Sept., 1985.

Burdon, D.J. (1985) "Temperature of Groundwater" Inter. Symposium on Groundwater", Taormina, Sicily, 17-21 Nov., 1985.

Burdon, D.J. (1987) "Some Ancient Dolines in the Karst of Ireland", Karst Meeting, Florida Sinkhole Research Institute, Orlando, Florida, USA.

Burdon, D.J. (1987) "Energy from Groundwater" IAH Mem. Vol.XX, Rome Congress, Italy.

Burdon, D.J. (1987) "Ordovician Volcanics of Ireland" Contribution to the IAH Commission on the "Hydrogeology of Volcanic Terrain".

Burdon, D.J. (1987) "Dinantian Volcanics of Ireland" Contribution to the IAH Commission on the "Hydrogeology of Volcanic Terrain".

Burdon, D.J. & Cullen, K.T. (1980) "The Hydrochemistry of Caradocian Volcanics in South-East Ireland" Fourth Inter. Sym. on Groundwater, Catania, Sicily, Italy.

Burdon, D.J. & Burns, D.J. & Peel, S. (1983) "Geothermal Energy Investigations in Ireland" EEC "European Geothermal Update" Munich.

Burdon, D.J. & Drew, D. (1986) "Hydrogeology of Selected Areas of the Karst of Ireland" Submission to the IHD Karst Commission.

Burke, W. (1972) "Aspects of the Hydrology of Blanket Peat in Ireland" Inter Symp. on the Hydrology of Marsh-Ridden Areas, Minsk, UNesco, Paris.

Cullen, K.T. (1978) "A Preliminary Hydrogeological Investigations of South Co. Wexford, Ireland". Thesis, Univ. of Birmingham.

Daly, D. and Misstear B. (1976) "A Preliminary Hydrogeological Study of the Castlecomber Plateau" M.Sc. Birmingham Univ.

Daly, E.P. (1974) Thesis at North Carolina Univ.

Daly, E.P. (July, 1978) "Field Trip to the Nore River Basin" Irish Meeting of the European Association of Exploration Geophysicists.

Daly, D., Lloyd, J.W., Misstear, D.R. & Daly, E.P. (1980) "Fault Control of Groundwater Flow and Hydrochemistry in the Aquifer System of the Castlecomber Plateau, Ireland" QJEG, Vol.13, pp.167-176.

Daly, E.P. & Daly, D. (1982) "A Study of the Nitrate Levels in the Aquifers of the Barrow River Valley, Ireland" IAH Mem. Vol.XVI. Congress of Prague Czechoslovakia, pp.183-194.

David, H.V. (1984) "The Role of NGO's in Development Projects" GORTA Seminar on "Water and the Third World, Dublin, 16 Oct., 1984 - European Environmental Bureau.

De Wit (1979) "Water in the Mallow Area, Co. Cork, Ireland" M.Sc. Thesis, Free Univ. Amsterdam.

De Buissonje, B. (1977) "A Hydrogeological Survey in the Upper Ow River Catchment, Co. Wicklow" Thesis, Free Univ. Amsterdam.

Dooge, J. (1959) "A General Theory of the Unit Hydrograph" Jour. Geophy. Research, Vol.64, No.2.

Dooge, J. (1972) "The Water Balance of Bogs and Fens" Inter Symp. on the Hydrology of Marsh-Ridden Areas, Minsk; UNesco, Paris.

Dooge, J. (1984) "Water and the Third World" GORTA, Seminar on "Water and the Third World", Dublin, 16 Oct., 1984.

Dooge, J. & Keane, R. (1972) "Mathematical Simulation of Runoff from Small Plots of Undrained and Drained Peat at Glenamoy" Inter Symp. on the Hydrology of Marsh-Ridden Areas, Minsk, UNesco, Paris.

Drew, D.P. (1973a) "Hydrogeology of the north Co. Galway and south Co. Mayo, Lowland Karst Area, Western Ireland" Proc. 6th Inter. Speleology Congress, III.

Drew, D.P. (1973b) "Ballyglunin Cave, Co. Galway, and the Hydrology of the Surrounding Area" Irish Geog. Vol.6, pp.610-617.

Drew, D.P. (1984) "The Effect of Human Activity on a Lowland Karst" in the IAH Karst Commission "Hydrogeology of Karstic Terrains - Case Histories", pp.16-19.

EEC (1979) "Protection of Groundwater aginst Pollution caused by Certain Dangerous Substances". Council Directive No. 80/68/EEC of 17 Dec. 1979. Ireland by Aldwell and O'Boyle.

EEC (1982) "Groundwater Resources of the European Community" No.16, Ireland, by C.R. Aldwell.

Gorham, E. (1957) "The Chemical Composition of some Western Irish Fresh Waters" Proc. RIA Vol.58-B, pp.237-243.

Kempers, R. (1981) "A Hydrogeological Reconnaissance Study of the River Araglin Catchment, Co. Cork, Republic of Ireland" A thesis prepared by a graduate of the Free University of Amsterdam.

Luv, P.N. (1980) "The Role of Soil Moisture on Catchment Hydrology & Drainage" Ph.D Thesis, Queen's, Belfast.

Lynn, M.A. (1982) "Hydrology in Ireland" - A contribution to the UNesco International Hydrological Programme by the Irish National Committee for the IHP.

McCumiskey, L.M. (Nov., 1986) "The Central Region Rural Water Supply Project, Sudan" Paper to Irish "Engineering Group for Third World Development; An Foras Forbartha.

Mulqueen, J. (1975) "Drainage of Deep Peat in Ireland" Proc. International Symposium on Peat in Agriculture and Horticulture" pp.250-265.

Mulqueen, J. & Harrington, D. (1976) "Some Applications of Physics in the Development of a Gravel-Filled Mole Drain" in "Physics in Industry", pp.515-517, Pergamon Press, London.

Mulqueen, J. & Gleeson, T.N. (1981) "Some Relationships of Drainage Problems in Ireland to Solid and Glacial Geology, Geomorphology and Soil Types" Proc. Seminar in the EC Programme of Co-ordination of Research on Land Use and Rural Resources, Cambridge, United Kingdom. Ed. M.J. Gardiner.

Naughton, M.M (1978) "A Hydrogeological Study of the Upper Kilmanagh River Basin, Republic of Ireland, M.Sc. Thesis, Univ. Alabama.

Naughton, M.M. (1983) "Pollution of Tessan Springs, Co. Sligo" Irish Jour. Envir. Sci., Vol.II, An Foras Forbartha.

Nash, J. (1984) "Water Resources: Related Education and Research in the Third World" GORTA Seminar on "Water and the Third World", Dublin 16, Oct., 1984.

O'Connell, F.E. (1974) "Stochastic Modelling of Long Term Persistence in Stream Flow" Ph.D. Thesis, Imperial College, London.

O'Connor, K.M. (1975) "The Development of a Discrete Linear Cascade Model for Use with Hydrological Time Series" Dr. Tech., Tech. Univ. Budapest.

Peel, S. (Dec., 1984) "Four Towns Water Supply Project, Kingdom of Lesotho - Report on Groundwater Resources.

Reynolds, J. (1984) "Giant Dams and Fish Ponds" GORTA Seminar on "Water and the Third World", Dublin, 16th Oct., 1984.

Scanlon, B.R. (1983) "A Hydrogeological Study of the Maine River Basin, Republic of Ireland" M.Sc. Thesis, Univ. of Alabama.

Tratman, E.K. (Ed. 1969) "The Caves of North-West Clare, Ireland" Univ. Bristol Spelaeological Soc. David & Charles, Newton Abbot.

Von Ree, C.C.D.F. & Rot, G. (1981) "The Lower Carboniferous Limestone Aquifer near Buttevant, Co. Cork" A thesis prepared by two graduates of the Free University of Amsterdam.

Walker, S.T. (1963) "Evapotranspiration and Runoff in Northern Ireland" M.A. thesis, Queens, Belfast.

Walker, S.T. (1968) "The Water Balance of the River Lynher, Cornwall, Ph.D. thesis, Queens, Belfast.

Williams, P.M. (1966) "Limestone Pavements with Special Reference to Western Ireland" Pub. No.40, Institute of British Geography.

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Williams, P.M. (1971) "The Management of Ground Water Resources in the Republic of Ireland" QJEG, Vol.4, pp.334-335.

Williams, P.M., & Bowen, R. (1973) "Geohydrological Study of the Gort Lowlands and Adjacent Areas of Western Ireland using Environmental Tritium" Water Res. Research, Vol.9, pp.753-758.

Wright, G.R., Daly, D. & Daly, E.P. (July, 1983) "Groundwater Vulnerability and Quality in the Republic of Ireland" for the EEC Environment and Consumer Protection Service. Contract No.U(82)178-(543) D.G.XI.

Wright, G.R., Aldwell, C.R., Daly, D. & Daly, E.P. (1982) "Groundwater Resources of the Republic of Ireland" Ed. J.J. Fried. EEC DG for Environment, Consumer Protection and Nuclear Safety. Series 1404, Geol. Survey of Ireland.

Wright, G.R. (1984) "Work on Groundwater Aspects of the Peat Deposits of Senegal".

Wright, G.R. (1986) "Work on Development of Groundwater against Famine in Eritrea".

Van Patten, F.A.M. (1978) "A Hydrogeological Investigation of the Catchment Areas of the Low River, the Blackwater River and the Castlebridge River, Co. Wexford" Thesis, Free Univ. Amsterdam.

XII-2 First Irish International Hydrogeological Meeting, May, 1979

In all, nine scientific papers were presented to the session at TCD, Dublin on 25 May, 1979. There were guides to the field trips before and after the main meeting. And four of the members of the Karst Commission of the IAH contributed some valuable comments on the karst of Ireland. The papers are listed in order of presentation.

The Irish National Committee of the International Hydrological Programme has very kindly published these proceedings.

<u>Scientific Papers</u>

1. Williams, C.E. (1979) "Opening Address"

2. Aldwell, C.R. & Burdon, D.J. (1979) "Groundwater Investigations in Eire"

3. Bennett, J.R.P. (1979) "Hydrogeological Conditions in Northern Ireland"

4. Wright, G.R. (1979) "Groundwater in the South Munster Synclines"

5. Daly, E.P. (1979) "The Principle Aquifers of the Nore River Basin

6. Drew, D.P. (1979) "Limestone Hydrology in Clare and Galway"

7. Hartwell, D.J., Jordan, P.G. & Gutmanis (1979) "A Hydrogeological Study of the Aughinish Island Carboniferous Limestone, taking account of the Geological Features observed during Site Investigations and Subsequent Excavations"

8. Daly, D. (1979) "Confined Groundwater flow in the Westphalian Sandstones of the Castlecomber Plateau"

9. Cullen, K.T. (1979) "Aspects of the Hydrogeology of South County Wexford.

<u>Field Trip Guides</u>

1. Drew, D.P. & Plunkett-Dillon, E. (1979) "Guide and Field Notes for the Burren"

2. Daly, E.P. & Wright, G.R. (1979) "Field Excursion in the Nore River Basin and the South Munster Synclines"

<u>Contributions by Members of the Karst Commission</u>

1. Burger, A. (1979) "Brief Report on Hydrogeology of Karstic Terrains in Ireland"

2. Bono, P. (1979) "The Karst of Central-Southern Ireland; Impressions and a Working Hypothesis"

3. Le Grand, H. 91979) "Brief Note on the Hydrogeology of Irish Karsts"

4. Zotl, J.G. (1979) "Remarks on the IAH Meeting 1979 in Ireland".

XII-3 Second Irish International Hydrogeological Meeting, June 1984

This meeting was a joint meeting of An Foras Taluntais and the Irish Group of the IAH. Five scientific papers were presented at Johnston Castle. Three scientific papers were presented at Moorepark. Three scientific papers were presented at Creagh, Ballinrobe. There was a one-day field trip, for which David Drew prepared a field guide.

The Irish national Committee of the International Hydrological Programme has again very kindly published these proceedings.

Scientific Papers, at Johnston Castle

1. Aldwell, C.R. (1984) "Groundwater and its Use in Ireland". Geological Survey

*2. Lee, J. (1984) "Aspects of Agricultural Land Use in Ireland" An Foras Taluntais

*3. Toner, P.F. (1984) "Impact of Agriculture on Surface Water in Ireland - Part 1, General" An Foras Forbartha

*4. Sherwood, M. (1984) "Impact of Agriculture on Surface Water in Ireland - Part 2, Prospects for the Future" An Foras Taluntais

5. Daly, D. (1984) "Groundwater Quality and Pollution in Ireland" Geological Survey

Scientific Papers, at Moorepark

6. O'Kiely, P. (1984) "Silage in Ireland" An Foras Taluntais

7. Wright, G.R. (1984) "An Outline of the Hydrogeology of the Southern Water Resources Region" Geological Survey

8. Tunney, H. (1984) "Management and Disposal of Farm Wastes" An Foras Taluntais.

Scientific Papers, at Creagh

*9. Ryan, D. (1984) "Agricultural Drainage Practices in Ireland" An Foras Taluntais

*10. Burdon, D.J. (1984) "Hydrogeological Aspects of Agricultural Drainage in Ireland", Minerex Ltd., Dublin.

*11. Mulqueen, J. (1984) "Hydrology and Drainage of Peat" An Foras Taluntais.

The six papers marked with an asterisk have also been published in Environmental Geology, Vol.9, 1986.

Field Trip Guide

Drew, D. (1984) "The Burren Karst and Limestone Lowlands of Co. Galway", Trinity College, Dublin.

GROUNDWATER RESOURCES IN LESOTHO

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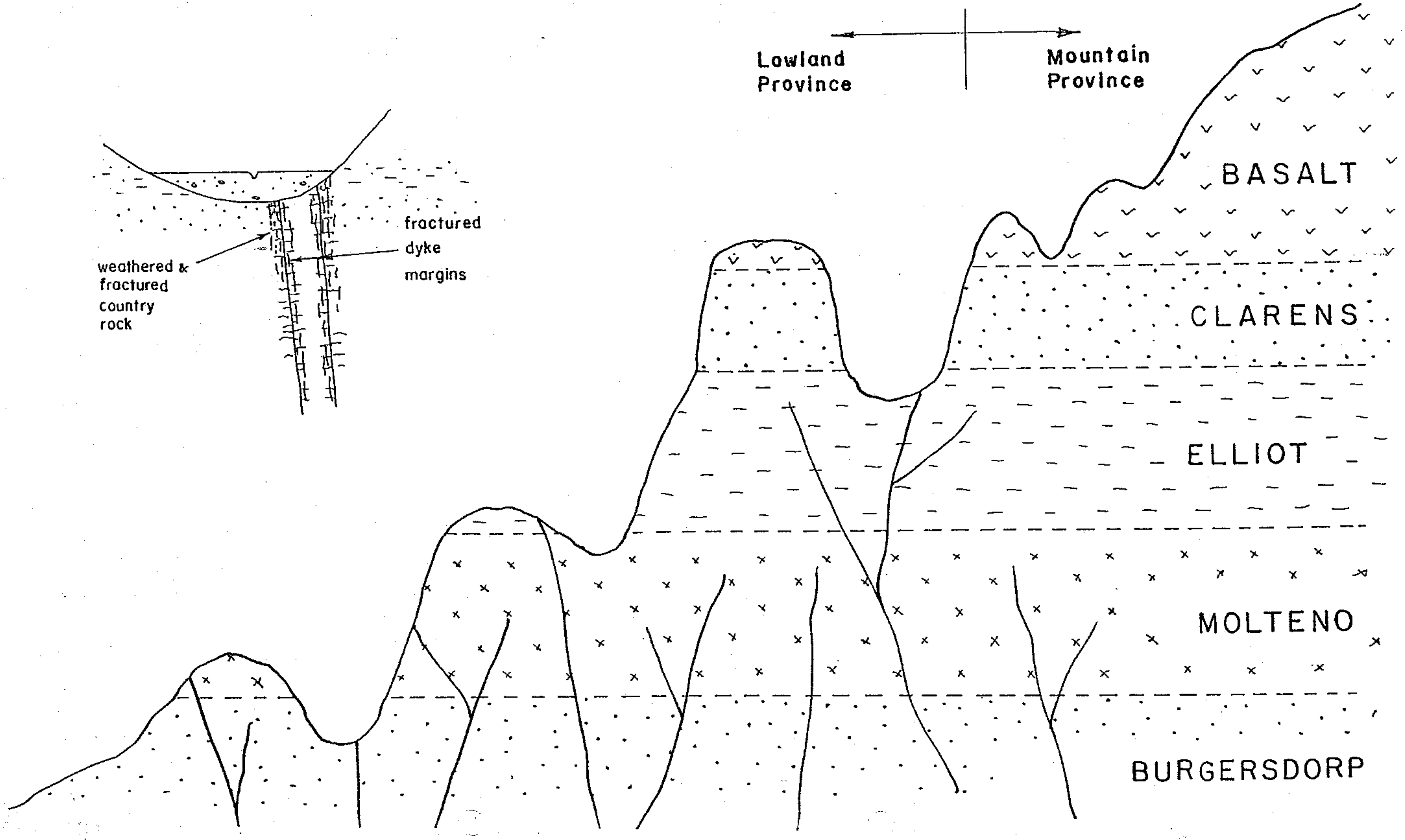
LESOTHO

SIMPLIFIED GEOLOGICAL SECTION



Groundwater Resources in Lesotho

1. Physical Features

The Kingdom of Lesotho is completely surrounded by the Republic of South Africa and occupies an area of 30,344 km^2, that is about half the area of Ireland. It is situated at the highest part of the Drakensburg escarpment on the eastern rim of the South African plateau, and about two-thirds of the country is very mountainous. Elevations in the eastern half of the country are mostly above 2440 metres, and in the north-east and along the eastern border exceed 3350 metres (11000 feet). This is a region of very rugged relief with deeply-cut valleys. the main drainage features are the Orange (Senqu) River which flows from the western mountainous area to the south and west and the Mohokare River which flows along the western border. Elevations decrease to the level of the high veldt in the west at about 1500 metres.

2. Population, Economy and Natural Resources

The population of Lesotho is about 1.4M and at this level the country has been described as severely overpopulated in view of the large proportion of uninhabitable and uncultivable land in the east. Only one eighth of the land is cultivable. Population pressure has resulted in :

i) permanent settlement up to 2440m in areas previously used for summer grazing

ii) very serious soil erosion, particularly in the west

iii) the country's inability to support all its population.

This last point has led to migration of labour to South Africa and there is a great economic dependancy on that country. The Lesotho currency is tied to the S.A. Rand.

The Lesotho economy operates according to 5 year economic development plans. Recent priorities have included improvements in the use of land and water resources and creating domestic employment. A third of planned investment is allocated for the development of infrastructure.

The country has limited natural resources which have been listed as people, water and scenery. There is little manufacturing industry and at present the main mineral export is diamonds which occur in hundreds of kimberlite pipes and dykes in the eastern highlands.

Lesotho is one of four main countries which receives aid from Ireland through the Bilateral Aid Programme run by the Development Cooperation Division of the Dept. of Foreign Affairs. It is also the recipient of aid from several other countries.

3. Water Resources

The eastern mountainous region has the highest rainfall in southern Africa up to 1900 mm p.a.. In the western lowlands the annual total is about 500 mm; the average for the country being 700 to 800 mm p.a.. Rain falls mainly in the months October to April and snow on the highest mountains is normal during some months, causing the isolation of some villages.

Evapotranspiration has been estimated at 82% of precipitation and from river gauging data an overall figure for surface runoff of 140 mm p.a. is indicated, equivalent to 130 m^3/s. Owing to shortage of winter runoff, winter stream discharges are attributed to baseflow.

With regard to water resource development the major plan is for the Highlands Water Scheme. This is an ambitious plan to direct the headwaters of the Orange (Senqu) River in Lesotho into the Vaal River to the north, and thereby ensure adequate water supplies for the Johannesburg/Pretoria region. Such a scheme would also incorporate hydro-electrical power generation with enough capacity to supply all of Lesothos needs. The scheme is to be a joint one, with equal financing from South Africa and Lesotho. To assist Lesotho with this financing the Project is receiving 9.5 M ECU from the European Development Fund.

4. Water Supply

The largest towns are located on rivers and rely on surface water supply. There are some conventional river intakes with associated treatment works but the very high level of suspended solids in the waters of the lowland rivers make treatment expensive. The alternative means of abstraction is from river bed sediments using infiltration galleries or large diameter wells. Experience has shown that these too need a high degree of maintenance if they are to remain in service for the required period. The majority of the population do not live near a perennial surface water source however and many live a high altitude. Many therefore rely on groundwater using low yielding village wells. For some years now aid programmes have been involved in drilling village wells to meet these needs.

5. Geology

The geology of Lesotho is relatively simple, consisting of a succession of sedimentary formations capped by a series of basalts as shown below;

Formation	Period	Thickness (m)	Rock types
	Quaternary	-	Alluvial sands & gravels
Lesotho	Lower Jurassic	2000 max	basalt
Clarens	Upper Triassic	100 - 200	sandstones
Elliot	Upper Triassic	15 - 250	mudstones & sandstones
Molteno	Upper Triassic	15 - 350	predominantly m/c grained sandstone
------- unconformity -------			
Burgersdorp	Middle Triassic	-	mudstones and siltstones.

All of the consolidated formations are horizontally bedded.

An important feature throughout the country are swarms of dolertie dykes intruded into all of the strata. These occur in decreasing numbers at higher elevations.

The Lesotho basalts outcrop over most of the country and owing to the horizontal bedding of the strata and the drainage pattern, the underlying formations outcrop successively in a western direction.

6. Aquifers

The sedimentary formations have not been extensively investigated regarding aquifer characteristics, but in general they are not regarded as aquifers. This is because sandstone facies within them are generally impersistent and what investigations there have been have produced poor results. This is in part due to the limited recharge that occurs. The Lesotho basalts too are poor aquifers, seeming to lack any significant scoriaceous or weathered zones.

The only proven aquifers in the country are dykes and metamorphosed country rocks adjacent to them. Weathering is an important feature with regard to aquifer formation so only near-surface dykes are considered worthy of investigation. The dykes tend to be intensely jointed parallel to and perpendicular to the contact surface especially close to the contact. Spheroidal and columnar weathering of the dolerite exists and enhances aquifer properties whereas in some places the dolerite has been weathered to a state of disintegration.

Where metamorphosed, sandstones have been recrystallised and mudstones altered to hornfels. In places where joints have been opened by weathering these contacts zones develop permeability and storage.

7. Groundwater Resources & Investigation

Estimates of infiltration to the various formations are as follows : -

Basalts 30 mm p.a.
Molteno "
Other sedimentary formations 15 mm p.a.

These would result in only modest groundwater recharge and in order to take best advantage of this, groundwater should be abstracted from weathered dykes at topographically low locations having relatively large catchments. Such locations close to river channels might in addition benefit from recharge from river bed sediments.

The whole country has been geologically mapped at scales of 1:50000 or 100000, partly using photogeology methods. These maps show the intrusives in detail and are very useful for locating dykes on the ground, many of them being exposed in river channels. Where dykes are not visible magnetometer surveys can be used to locate them and resistivity surveys can be used to determine depths of weathering beyond which drilling need not go. Resistivity surveys can also be used to determine the depth of sills. In South Africa, the use of geophysical surveys in this way has resulted in a 50% saving on total investigation costs over the cost of investigation not using this approach to locate dykes.

In Lesotho there are only basic borehole data and very little test pumping has been done. The success rates of boreholes drilled into or near to dykes has varied greatly. In some holes water is found in dykes, in others it is found in the contact zone and some are found to be completely dry.

8. Four Towns Water Supply Report

Nicholas O'Dwyer and Partners were awarded a contract to design water supply schemes for four of the main towns in Lesotho. All potential sources of supply were to be investigated and Minerex Ltd. were employed to undertake an assessment of groundwater potential for all four towns. Much useful information was obtained from Government Departments in the Capital Maseru and dykes in favourable positions were located on site. Recommendations for well drilling with indications of groundwater potential were subsequently given.

Acknowledgment

The author is grateful for the assistance of Nicholas O'Dwyer & Partners in the preparation of this paper.

THE APPLICATION OF REMOTE SENSING, STRUCTURAL GEOLOGY AND HYDROGEOLOGY TO THE SEARCH FOR NEW GROUNDWATER RESOURCES IN THE ADRAR DES IFORAS MASSIF IN NORTH EAST MALI.

1. BACKGROUND.

The Adrar des Iforas Massif is a highland area covering approximately 750,000 km² in the north east of the Republique du Mali. The area is very remote and access is restricted. The highest part is in the north where summits reach over 800 metres. The rest of the area lies between 500 and 600 metres. The landscape is composed of abrupt black rock masses that rise from a subdued, undulating peneplain of sand and gravel. The rocks of the area are mostly igneous and metamorphic, ranging in age from Archaean (>2,170 million years) to Cambrian (570 million years). The area experiences a desert climate with erratic rainfall of 75-150 mms, in July and August, and low humidity. The vegetation is very sparse and largely consists of ephemeral grasses on the clay floor of the lowland wadis (oueds) and isolated mature bushes and trees along the flanks of the most active water sources. The population is very sparse, approximately 15,000-20,000 persons, of which 25% are found in the regional centre, Kidal. There are three other major villages and the rest of the population are Tamasheq nomads, many of whom have lost all their animals during the drought up to 1985.

2. WORK PROGRAMME AND METHODOLOGY.

The purpose of the research was to try and combine image processing, with remote sensing and field work by experienced structural geologists and hydrogeologists. It was hoped that, by this combination potential targets for future groundwater exploration could be identified in ancient hard, brittle rocks in this desert area. The identification of new water sources in an area with such a high level of need was a considerable challenge.

David M. Ball, Environmental Resources Analysis Limited, 187 Pearse Street, Dublin 2.

(Carried out in Conjunction with Direction Nationale de la Cartographie et Topographie, Bamako, and Servizio Geologico d'Italie, Roma for the Commission des Communautes Europeennes, Bruxelles and J.R.C. Ispra, under Project 958(83) Tel-1 "Caracterisation par les techniques de la teledetection de la dynamique de la desertification a la peripherie du Sahara").

The work programme can be summarized as follows: acquisition and processing of recent Landsat MSS (rainy season) and TM (dry season) imagery; acquisition of SIR A radar and archive MSS imagery; lineament mapping and statistical analysis of lineament orientation and density; detailed structural and hydrogeological remote sensing and interpretation; two months field work measuring geological features, wells and boreholes combined with local discussions on development requirements; technology transfer by inviting Dr Amadou Coulibaly, a Malien counterpart, to Dublin for hand-on experience in geological remote sensing; and analysis and report writing.

The methodology involved a careful integration of remote sensing using computers, statistics and image processing software with detailed interpretation. The image processing was carried out in order to maximize the information available on geological structure and lithology and also vegetation, soils and hydrology. Dry season 30-metre resolution TM imagery was used in order to compare the benefits of the increased detail, and also seasonal conditions, with the 80-metre resolution August MSS imagery. Several edge enhancements, ratioing and principle component analyses were used to bring out the required information. The geological research was approached from two standpoints. The first was centred around lineament analysis and statistics in order to see whether preferred orientations of linear features or density of lineaments provided evidence for selecting groundwater targets. The second standpoint was to start from basic principles of extensional tectonics and propose structural settings that were likely to provide brittle deformation and open fracture systems in the bedrock. These models combined with lithological information were then used as guides for the image interpretation.

The methodology of the hydrological investigations relied on an equal balance of image interpretation of vegetation, geomorphology and hydrology, and a ground survey of wells, water levels and water chemistry. An understanding was derived from this of rainfall, runoff and recharge regimes, aquifer occurrence, water quality variations and water requirements.

3. RESULTS AND RECOMMENDATIONS.

The application of the above methodology and the integration of interim findings and interpretations produced interesting and valuable results. These are summarized as follows:

a) Imagery: The MSS, TM and SIR A imagery all provided very useful information with different characteristics. In reverse order, the SIR A radar provided coverage with intense detail on the structural geology and revealed important features that were not readily evident from the multi spectral scanners. Though MSS is useful for obtaining regional information and understanding large scale structures, its usefulness is surpassed by the level of geological, vegetation and hydrogeomorphological detail obtainable from TM. As satellite borne radar is not available TM is the recommended imagery for future work of this nature.

b) <u>Lineament Analysis and Statistical Processing</u>: The results of this work indicate that the methods are relevant as a guide but by themselves only highlight zones for more detailed analysis. It is not possible to merely put lines into a "black box" and expect pin-point definition for future groundwater targets.

c) <u>Structure Geology Interpretation</u>: A combination of detailed structural geology analysis of the TM images, knowledge of neotectonics, ground data and lineament processing integrated by experienced personnel provides extremely rewarding results. By this method it has been possible to predict many areas where abundant open fractures are likely to exist and where the fractured lithologies are likely to be sufficiently resistant to weathering that the openings have not become clogged by residual products of the weathering process.

d) <u>Hydrogeology and Water Resources</u>: The interpretation of wet season and dry season imagery enables a sound understanding to be achieved of the water resources and rainfall-runoff-recharge regime. The abundance of vegetation in the oueds after the rains indicates the extent of runoff from the rock massifs on to the low gradient plains below. Many of the oueds do not contain flow along their entire course, many floods peter out in the flat clay pans. An interpretation of the drainage pattern indicates the presence of ancient drainage channels that may contain thick alluvial sediments. The detail on the TM scene shows bedrock constrictions that may form suitable sites for underground dams. Field assessment of the image interpretations by experienced personnel shows that the imagery can be used to derive realistic groundwater recharge models. Field data is still essential, but in combination with remote sensing it has been possible to refine the interpretations derived from structural geology and produce a list of firm groundwater targets worthy of further exploration and ultimately exploitation. A remote sensing and field based analysis of the structural and groundwater settings of the major water sources (Grands Puits) in the area shows that each one owes its existence to conditions previously identified as favourable by the methods described above. The most important discovery concerns for example a brittle mylonite zone, associated with a major north south sinuous shear zone along the western edge of the Iforas Granulite unit. A famous, and very reliable, Grand Puit named Rharous is situated precisely at a point where it was predicted that recent re-activation of the shear would have produced open fractures.

e) Development Concepts and Recommendations: The recent prolonged droughts have caused great loss of livestock and enormous suffering. Arising from this, the nomads are experimenting with the cultivation of basic food stuffs and supplementary fodder in small gardens around reliable wells. The development of jardinage (small scale agriculture) indicates a realism enforced by hardship. However, it must be recognized that if the pre-drought rainfall conditions reoccur then there will be a return to nomadism and pasturalism. In view of this it is important that the development of new groundwater resources is restricted in such a way that the abundant water does not lead to a rapid depletion of the fragile fodder resources and yet, at the same time, there is adequate water for the further spread of cultivation on suitable soils. The provision of abundant water in the wrong places could create a great disequilibrium between the fragile ecosystem and the dependent human and livestock resources. Too much groundwater could sow the seeds of an even greater disaster the next time the rains fail.

The area is very remote and it would be unrealistic to suggest that ground water abstraction could be achieved and maintained using boreholes and mechanical pumps. Instead it is recommended that pilot exploration holes are drilled, and where successful these are made accessible by the construction of adjacent, modern designed, traditional dug wells where water is raised by hand. The conclusions of the project suggest several judiciously spaced targets for this form of development. In each case the selected position is a point where the sandy bed of a wadi debouches out from a large catchment area of steep relief and bare rock, and where this wadi crosses a zone where the underlying hard bedrock has been intensely fractured and the fractures are expected to be open. Low barrages made from gabions are advocated in order to check the surface water flood and increase recharge into the alluvial aquifer. With time, the silt build up will provide soils for small gardens reliant on groundwater.

It is suggested that use of the TM imagery, sophisticated structural geology and hydrogeology remote sensing and field surveys is a successful technique, and such a study could be replicated and yield valuable results in other hardrock, low rainfall areas of the Sahel.

1. **El Obeid Water Supply, Kordofan Province, Central Sudan, 1974.**

Background: Low rainfall in 1973 led to water shortage in El Obeid (pop. 100,000) in the following dry season. Consultants were appointed to assess future needs and recommend means of ensuring adequate supplies up to the year 2000. Average rainfall in the area is about 400mm/yr, mainly in June/September.

Five alternative proposals:

(a) Expand existing system, based on surface impoundments
(b) Develop groundwater from Bara Basin, 60km away
(c) Develop surface impoundments at Er Rahad, 40km away
(d) Pump from White Nile at Kosti, 300km away
(e) Pump from Bahr-el-Arab, 500km away

Work Programme: Two-man team (Hydrogeologist and Engineer/Hydrologist) spent two months, mainly in Khartoum, with some time at El Obeid, Bara etc., to:

(a) Review present and future water needs
(b) Review present water system
(c) Review proposed alternative schemes, making technical and economic comparisons
(d) Recommend measures for immediate improvements, long term supply and programme of further investigation where necessary

Hydrogeological Work, Bara Basin.

Previous reports, logs of 160 boreholes, pumping test records and hydrochemical data were reviewed, and used to compile maps showing topography, depth to bedrock, piezometry and hydrochemistry. Aquifer properties were estimated, and used in 'modelling' possible abstraction schemes and effects on piezometric levels. Aquifer throughflow was estimated. Another groundwater basin was also briefly considered.

The Bara Basin comprises about 9000 sq. km of Umm Ruwaba Series sediments - terrestrial fluviatile and lacustrine deposits of Pliocene-Pleistocene age, laid down in a subsiding fault-bounded trough. Maximum recorded depth is about 540m but geophysical evidence suggests total depth may be 1.4km. The sediment ranges from clay to gravel, mostly poorly sorted but with some cleaner sand/gravel lenses, and is generally uncemented. Aquifer horizons are usually confined, and two flowing wells are known, though water levels are usually 10-30m below surface. Groundwater flow is to the south-east where the basin opens out.

Most drilling is by mud-flush rotary. Of over 150 boreholes, only 35 had even the most basic data for yield and drawdown, and only 11 had pumping test data. Specific capacities ranged from less than 1 to about 100 $m^3/d/m$. Estimated T values ranged from 1 to about 200 $m^3/d/m$, comparable with values for the same aquifer elsewhere in Kordofan. These T values were probably depressed by poor well construction and development and partial penetration. Median T was 12.6 $m^3/d/m$, and only 6 values were over 30. This proved to be very important.

Total aquifer storage is very large, equivalent to thousands of years of abstraction, but throughflow may be no more than 650,000 m^3/yr and may already be exceeded by abstractions. Hence abstraction for El Obeid would probably be mining. Recharge is very small. Water quality is good, with T.D.S. mostly below 1,000ppm.

Consideration of possible abstraction schemes, assuming various alternative numbers of wells, abstraction rates and well separations, showed that for a viable scheme a T value of at least 50 $m^3/d/m$ was needed. With lower T values, costs become too high because of:

(i) Too many boreholes needed, so capital costs of wells too high.

(ii) Boreholes need to be too far apart, to avoid interference, so capital costs of linking pipelines too high.

(iii) Drawdowns are too high, giving high pumping costs.

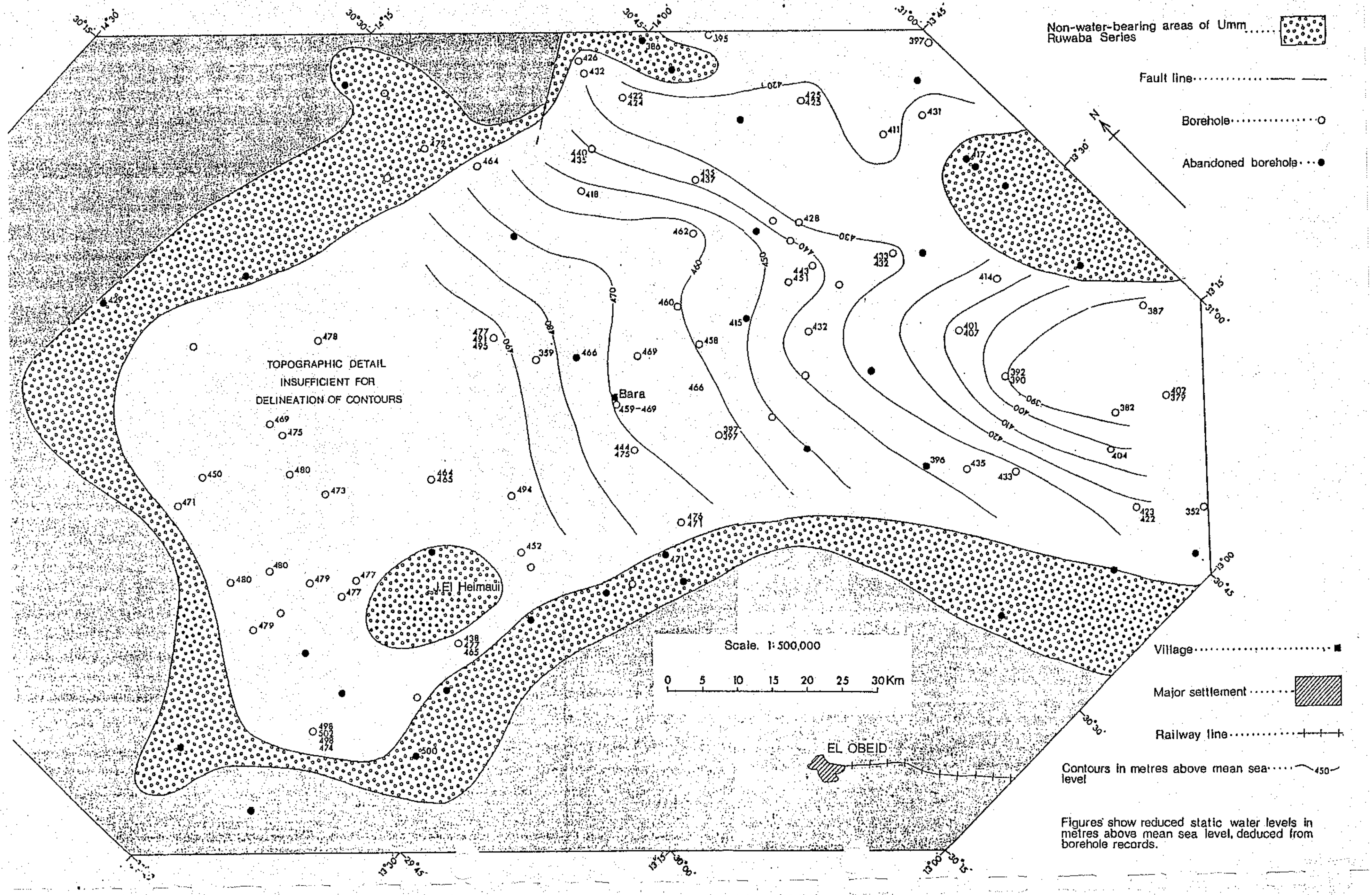
Since a regional T of $50m^3/d/m$ is unlikely on available evidence (only 6 wells indicated anything like this value), a Bara scheme was unlikely to be feasible. Further investigations to confirm this (or prove otherwise) would be quite costly.

Conclusion:

Water demand was estimated as 9500 m^3/d in 1980, rising to 17,500 m^3/d in 2000. The existing scheme, with some additions, could cope until 1980.

The White Nile and Bahr-el-Arab proposals were demonstrably several times more costly than the others, and not to be considered further. Of the two remaining alternatives, the Er Rahad scheme was likely to be feasible and to be less costly than the Bara scheme. Some technical questions at Er Rahad needed to be investigated and solved, at modest cost - principally whether storage dams would need lining or not. Only if Er Rahad needs very costly lining works should the Bara Basin scheme be considered further.

PIEZOMETRIC (WATER TABLE) CONTOURS



2. Senegal Peat Project, 1983

A Bord na Mona/ESB/GSI team was hired by a Senegalese Government agency, prompted by the European Development Fund, to oversee a pilot scheme for extracting peat. It was essential to monitor the effects of the extraction on the regional sand aquifer.

The peat occurs in shallow depressions (generally 3-10m) in between sand dunes. The dune sands comprise a regional aquifer and the peat bogs (locally 'niayes') were formerly lakes. As the water table fell in recent years, the peat began to dry out and become accessible.

The hydrogeological work was:

(a) To oversee a geophysical survey to define the location of the saline front along the nearby coast.

(b) To oversee the installation of monitoring wells in and around the pilot extraction area.

(c) To analyse and review the results of the monitoring of the water table and hydrochemistry.

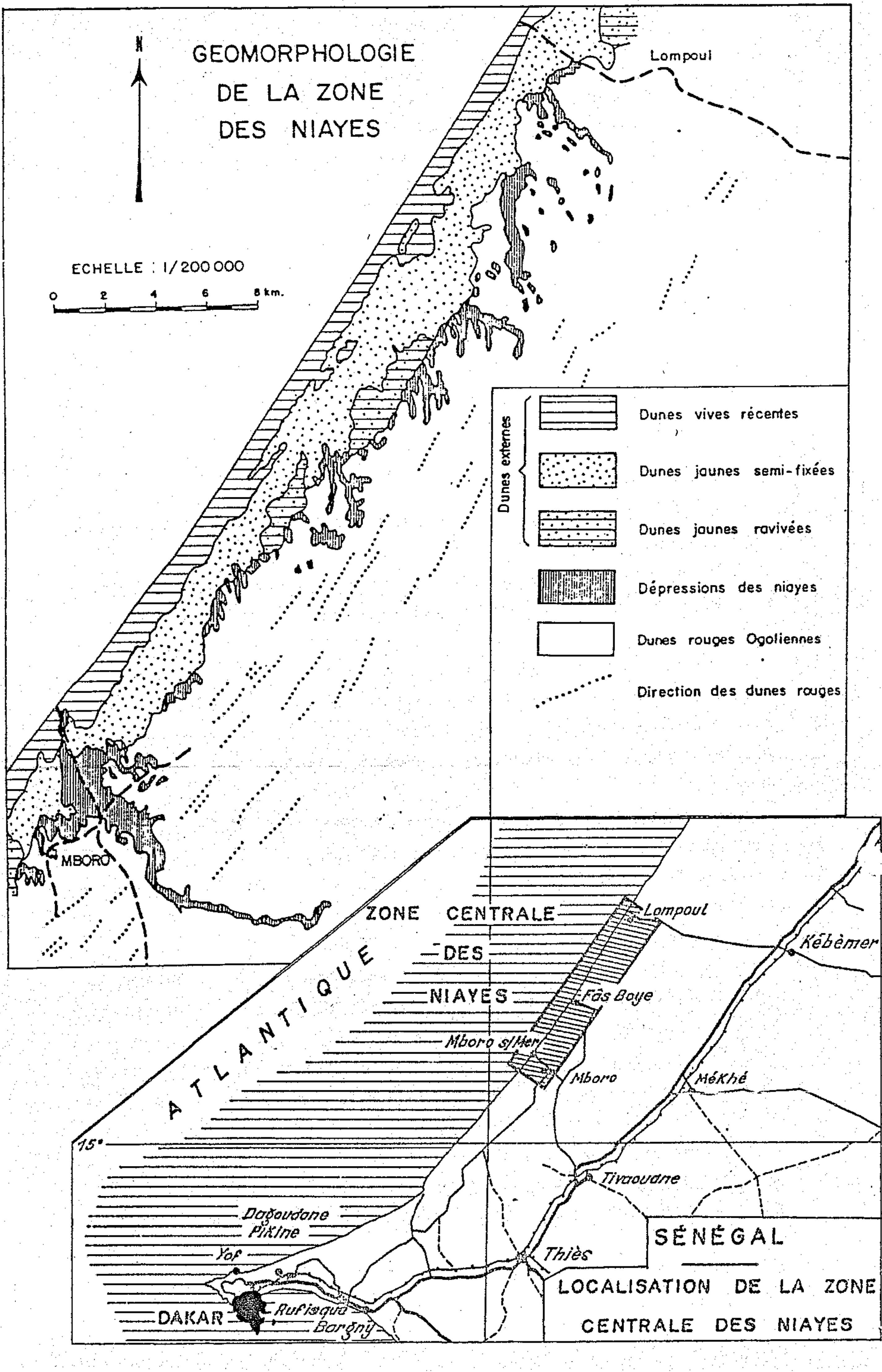
About four weeks were spent in the field, after which I returned to Ireland. Monitoring results were then sent on over the next few months.

Conclusions:

1. Saline front is a very narrow strip - mostly 100m wide, up to 300m near M'boro. Saline intrusion is no threat to aquifer at present.
2. Pilot peat extraction caused little disturbance to piezometry and little change in hydrochemistry, except for slight and favourable rise in pH.
3. Some recharge of aquifer took place even though rainfall was small, but the regional water table continues to decline.
4. Sustainable yield of aquifer (M'boro-Lumpoul) probably exceeded by present abstractions.

Main Recommendations

1. On the Saline Front - piezometric monitoring most important, new boreholes to be sunk to monitor water level and hydrochemistry. Geophysical surveys may be needed later.
2. On Peat Exploitation - In early years, niayes to be intensively monitored to build up experience of effects. Later, the monitoring can be reduced. Some auto monitoring at each site. Field chemical kits to be used, and daily rainfall measurement.
3. Quantification of Groundwater Resources - additional drilling, aquifer testing and modelling needed. Abstraction Survey and Management needed.
4. General - Peat project needs full time hydrogeologist and support. Co-ordination of various aspects needed.


GEOMORPHOLOGIE
DE LA ZONE
DES NIAYES
N
ECHELLE : 1/200 000
0 2 4 6 8 km.
Lompoul
MBORO
Dunes externes
Dunes vives récentes
Dunes jaunes semi-fixées
Dunes jaunes ravivées
Dépressions des niayes
Dunes rouges Ogoliennes
Direction des dunes rouges
ATLANTIQUE
ZONE CENTRALE
DES
NIAYES
Lompoul
Kébèmer
Fâs Boye
Mboro s/Mer
Mboro
MéKhé
15°
Tivaouane
Dagoudane
Pikine
SÉNÉGAL
Yof
Thiès
LOCALISATION DE LA ZONE
CENTRALE DES NIAYES
DAKAR
Rufisque
Bargny

3. **Iran, 1975**

Background: The Iranian Government had commissioned a report which highlighted the need to increase the per capita intake of protein, especially of dairy products. It was proposed to establish a number of livestock units in different parts of the country, to serve both as production units and as demostration farms. Each Dairy unit was to have around 500 milking cows, on a zero-grazing basis, feeding forage crops grown on site, using irrigation, and with cereals mostly bought in.

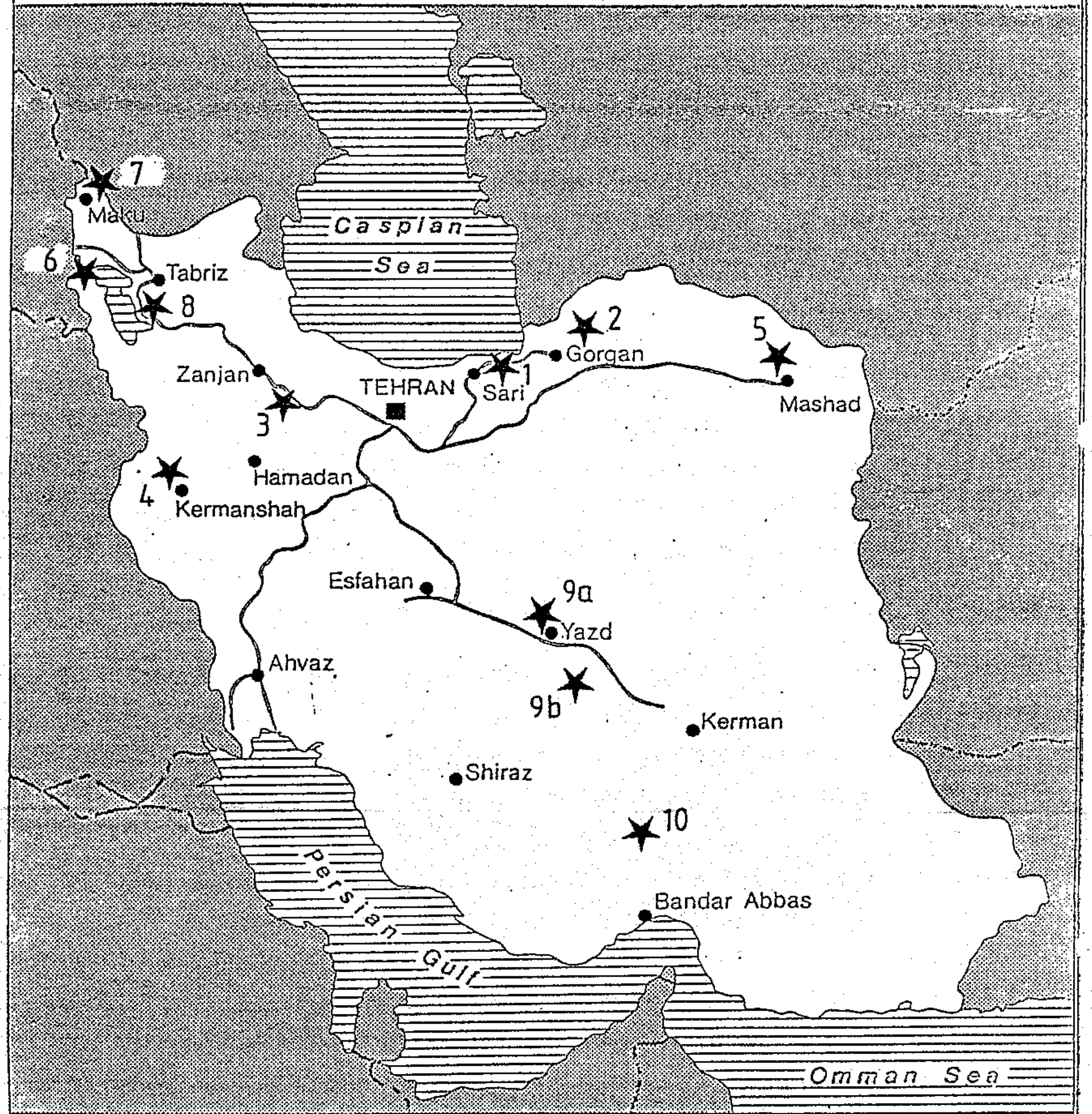
The land to be used was already in Government ownership acquired as a result of land reform measures.

Work: The Government had identified possible sites in ten areas, spread around the country (see Map). A six man team spent two months in the country - Soil scientist, hydrogeologist, agronomist, economist, poultry specialist and veterinarian. About 3 days were spent visiting each site, taking some measurements, reading relevant reports and talking to local officials.

Hydrogeology and Hydrology: For most sites, good reports were already available of at least reconnaissance standard. A little data was collected on site - EC measurements, water levels etc. The aquifers were almost always sands/gravels. Salinity was a problem in several areas.

Results: (See Table). In most cases there was sufficient data on water resources to reach a conclusion as to the availability or otherwise of sufficient water. All sites were acceptable for livestock rearing. The critical constraints were soils and water. The team was able to propose dairy units for three sites and other proposals for 3 other sites, dependent on other criteria.

Potential livestock sites under investigation



1	Neka ; 576 hectares		
2	Daland ; 1000 hectares	7	Zanganeh ; 12,000 hectares
3	Ghamichabad ; 1100 hectares	8	Mamaqan ; 1400 hectares
4	Mehregan ; 1300 hectares	9a	Charkhab ; 3200 hectares
5	Virani ; 600 hectares	9b	Bahadoran ; 9000 hectares
6	Aliabad ; 1200 hectares	10	Hajiabad ; 600 hectares

4. Eritrea, 1986.

In February-March 1986, I visited Eritrea (NE of Ethiopia, see Figure) as part of a two-man team to evaluate a water programme financed by a consortium of aid agencies.

Aims:

(a) describe and evaluate work already done.

(b) Identify gaps and suggest remedies.

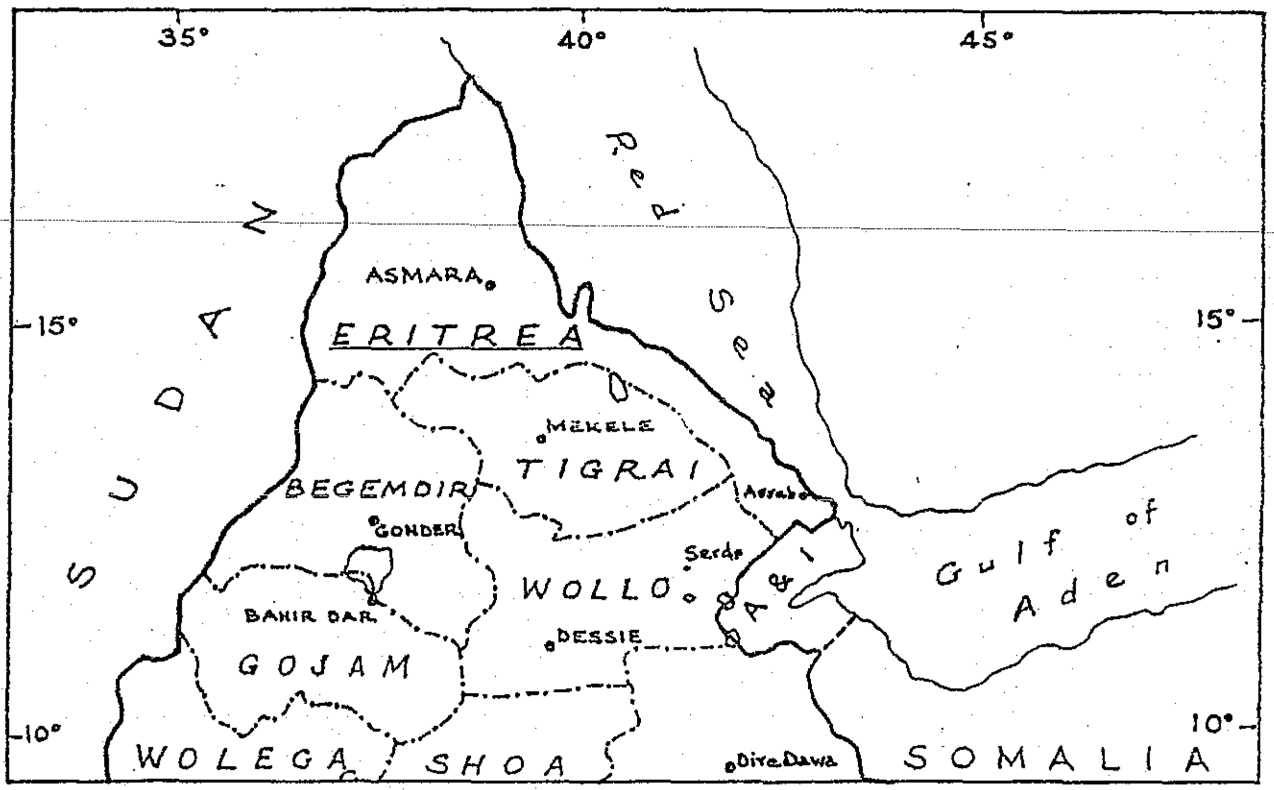
(c) Discuss issues arising to assist in assessment of further requests for aid.

Hydrogeology:

Two types of aquifers - Basement complex (metamorphic rocks) dependent on fissure flow, and river gravels, thin and variable. Previous development was dependent on on dug wells, but two recently arrived drilling rigs had trnsformed the programme, allowing very rapid development and exploitation of deeper water. Drilling operations were going very well.

Recommendations:

1. Need for urgent supply of meteorological and hydrogeological instruments already ordered.
2. Need for wellscreeens for gravel and sand aquifers.
3. Need for mobile pumping test units.
4. Need for greater sanitary protection for dug wells, with hand pumps.
5. Emphasis on data recording, keeping up with drilling programme.



SITE	ALT. m	RAIN FALL mm/yr	MEAN TEMP DAILY MAX (S) °C	MEAN TEMP DAILY MIN (W) °C	MEAN R.H. %	AVAILABLE AREA, ha	SOILS	SURFACE WATER	GROUND WATER	RECOMMENDATION
1	50	700	30	5	75-80	576	Heavy texture, Low permeability. NOT RECOMMENDED	SOME (about 2/3 of needs)	SOME (about 1/3 of needs)	UNSUITABLE No proposals
2	120	680	35	3	67-72	1000	O.K.	NONE AVAILABLE	O.K	DAIRY ENTERPRISE PROPOSED on 600 ha
3	1500	< 400	30	-6	50	1100	O.K.	NONE AVAILABLE	O.K.	DAIRY ENTERPRISE PROPOSED on 630 ha
4	1400	470	38	-4	48-52	1300	O.K.	SOME but groundwater better	O.K.	DAIRY ENTERPRISE PROPOSED on 300 ha
5	1100	220	33	-5	50-54	600	UNSUITABLE very stony	NONE	AQUIFER ALREADY OVERDRAWN	UNSUITABLE No proposals
6	1330	400	30	-4	55-60	1200	ONLY 250 ha. SUITABLE	ONLY IF DAMS BUILT (SHAHPUR PROJECT)	ENOUGH FOR < 200 ha	BROILER POULTRY UNIT PROPOSED; SHEEP PROJECT POSSIBLE IF SHAHPUR BUILT
7	1500	260	33	-7	65-70	12000	DIFFICULTIES IN RECLAMATION & MANAGEMENT	O.K.	UNLIKELY (NO INFO.)	UNSUITABLE No proposals
8	1300	380	33	-7	50-55	1400	UNSUITABLE Saline	NONE AVAILABLE	Low yields & salinity — NOT FEASIBLE	UNSUITABLE No proposals
9a	1240	< 100	39	-2	40	3200	ONLY 200 ha SUITABLE	NONE	AQUIFER O/DRAWN WATER ALLOCATION DOUBTFUL	BROILER POULTRY UNIT PROPOSED; DAIRY UNIT POSSIBLE IF WATER ALLOCATED
9b	1600	< 100	36	-5	40	9000	UNSUITABLE	NONE	LOW RECHARGE (Little info.)	UNSUITABLE No proposals
10	900	< 200	> 40	6	30-35	600	c. 200 ha SUITABLE	NONE	AQUIFER O/DRAWN SOME SALINITY	BROILER POULTRY UNIT PROPOSED; LIMITED DAIRY UNIT POSSIBLE.