Irish Group

International Association of Hydrogeologists

Groundwater and Regional Water Supply

Tuesday 7th April **Speaker and Organisation**

Session 1 : Chairman - Kevin Cullen : Groundwater and regional Supply Schemes

10.15	Registration and Coffee	---
11.00	Welcome and Introduction by Chairman for session	Kevin Cullen K.T. Cullen Hydrogeological Services
11.15	Overview of Status of Regional Water Supplies in Ireland	Gerry Galvin Nicholas O'Dwyer + Ptnrs
11.45	Current large ground water abstractions, their status and potential in economic terms.	Don O'Sullivan Wexford Co. Co.
12.15	Discussion	---
12.45	LUNCH	

Session 2 : Chairman - Shane O'Neill : Groundwater exploration and development

14.15	Overview of groundwater resources in Ireland	Bob Aldwell Geological Survey of Ireland
14.35	Indirect methods : Remote sensing and Geophysics	Ger Kehane Fuego - Mc Clelland
14.55	Well Testing	Kieran O'Dwyer K.T. Cullen & Co.
15.15	Modelling - Aquifer Vulnerability; Well Head Protection; Management of Resources.	Colin Smith Consultant Hydrogeologist. (U.K.).
15.35	Discussion	---
16.00	COFFEE	
16.30	Interaction of large groundwater abstractions, legislation,treatment and economics.	Dave Cooke Thames Water Utilities
17.15	Discussion	---

Groundwater and Regional Water Supply

Wednesday 8th **Speaker and Organisation**

Session 1 : Chairman - Frank Clinton : Treatment and distribution of groundwater

9.15	Assessment of Water Balance for Regional Water Resources	David Ball
9.35	Case study of assessment of water resource of an Irish river catchment	Dr. Tommy Bree E.S.B. International
10.05	Discussion	
10.15	COFFEE	

Session 2 : Chairman - Kieran O'Dwyer : Problems with groundwater

10.45	Overview of groundwater in relation to statutory regulations	Dr. P.J. Flanagan Environment Research Unit
11.05	Microbiology of groundwater	Dr. Ronnie Russell Trinity College, Dublin
11.25	Results of recent trihalomethane study of public water supplies	Ciaran O' Donnell Environment research Unit
11.45	Interpretation of a typical water analysis	Richard Foley Eolas
12.05	Trade talk on the treatment of Iron and Manganese	Michael Hoole Halpin and Heyward
12.25	Discussion	

NOTE: GOLF OUTING ORGANISED FOR THE AFTERNOON OF THE 8th.

THE STATUS OF

REGIONAL WATER SUPPLY SCHEMES IN IRELAND AN OVERVIEW OF DEVELOPMENTS

GERRY GALVIN

NICHOLAS O'DWYER AND PARTNERS

This paper considers likely developments in regional water supplies in Ireland and discusses the role groundwater can play. A number of recent developments in Europe which will have very significant implications on water supply in this country are also discussed.

It is now almost thirty years since the first Regional Water Supply Scheme (Galtee Scheme in South Tipperary) was developed. Since then regional schemes have been developed in every county in the country throughout the sixties, seventies and eighties. The sources developed (river, lake or groundwater) and the type of treatment (if any) employed vary as does the scale of the schemes. However the aim of each scheme is now identical, to produce potable water meeting the standards required by the Drinking Water Regulations SI No. 81 of 1988 and to reliably distribute this water to each household within its supply area.

With the increase in public awareness of environmental issues over the past decade the approach to developing and running a Regional Water Supply Scheme has undergone radical changes. The emphasis is now more on maintaining the quality of the supply at all times notwithstanding seasonal variations in raw water quality, than it was for the earlier schemes. Where treatment of the raw water is required, a greater degree of process control and monitoring is essential to ensure compliance with the standards in particular for parameters such as residual aluminium. Equally careful consideration must now also be given to the safe disposal of process water and sludges resulting from water treatment.

To date groundwater has not had a role in the majority of regional schemes developed. However, this may change rapidly, as schemes developed in the sixties and seventies are now assessed by today's standards. Such assessment should review

a) the quality of the source and its seasonal variations as well as comparing how this may have changed since the scheme was first developed

b) the existing treatment process and its present effectiveness

c) the monitoring and recording of quality parameters

d) the existing treatment (if any) and disposal of process waters and sludges.

If deficiencies are identified during this review, corrective action may involve one or more of the following:-

1) Replacement or augmentation of the original source with a new surface or groundwater source.

2) Modification or extension of the treatment units.

3) Modification to the treatment process e.g. installation of lamellae plates in clarifiers, conversion of filters to deep bed monograde sand or pH adjustment.

4) Thickening and dewatering of process waters and sludges.

5) Installation of telemetry systems to monitor and control the scheme thus providing early warning of any deficiency in quantity or quality.

As the publics growing interest in such matters increases, the monitoring and storage of quality records which are readily retrievable will become ever more important. A lack of knowledge will no longer be acceptable where matters of public health are concerned as the public will tend to regard no news as bad news.

As identified above groundwater may have an important role to play in replacing or augmenting existing sources. In developing a new groundwater source for an existing regional water supply scheme a number of important points must be considered in addition to the usual considerations of reliable yield, aquifer protection etc.

Where the preparation of an environmental impact statement is required for a groundwater scheme to comply with Directive 85/337/EEC, the accurate mapping of the aquifer will be necessary together with the collection of sufficient data to fully assess the effects of the proposed abstraction.

The effects of introducing a new groundwater with different characteristics into an existing scheme need careful consideration. Blending may be desirable to alleviate potential problems with differences in hardness. Where flow reversal in distribution mains occurs from the introduction of the new source, a deterioration in the quality of water supplied to the consumer may occur initially. This is a result of deposits/ encrustation on the pipelines becoming dislodged in particular in cast iron mains requiring at the very least the scouring of the distribution mains or where such conditions persist, pigging of the mains may be necessary.

The European Commission has already begun work on reassessment of the parameters set down in the E.C. Directive relating to the Quality of Water Intended for Human Consumption 80/778/EEC and their implementation including the methods of analysis to the employed. The MAC values in the directive were originally agreed by consensus among the then member states without the basis for deriving the values being set down.

As part of this review the U.K. are seeking to increase the MAC values for nitrates above the 50 mg/l set while they are also seeking the revision of the taste and odour parameters to provide more sensible, fully documentated standards and a standard analytical method for these parameters to guarantee comparable results.

The case is also being made at present to depart from the consensus approach for setting these standards to a 'risk assessment' approach to determine allowable levels for parameters which effect human health with guideline values of an advisory nature being recommended for the remaining parameters. The likely outcome is that the allowable values for some of the parameters will become more stringent.

Where groundwater is concerned, our fellow EC states are so highly dependant on groundwater as a source of supply as shown in Table No. 1, that policies and standards will be set on the continent which we in turn will have to adopt or amend as necessary to meet our requirements

TABLE NO. 1	**GROUNDWATER AS PERCENTAGE OF TOTAL SUPPLY**
Denmark	98%
Italy	85%
Germany	75%
The Netherlands	70%
France	60%
United Kingdom	35%
Spain	25%

Figures taken from World Water and Environmental Engineering January/February 1992.

The EC have been relatively slow in admitting that groundwater pollution and contamination of aquifers is the most important issue to be faced in relation to the long term adequacy of their water supplies. However in late November the EC Environment ministers agreed proposals for future action. They recognised that sustainable use of groundwater requires the preservation of existing quality at a correct level and the prevention of a long-term permanent overdraft and so demands an integrated approach at all levels. This concept of a integrated approach is both scientific and political.

On the scientific side, the approach is that surface and groundwater should be managed as a whole paying equal attention to both quantity and quality aspects. On the political side, water quality management policies should be integrated within the wider environmental framework and other policies dealing with human activities.

An action plan proposing three categories of action was accepted.

i) Mapping and monitoring groundwater resources including protection zones, abstraction permits, polluting activities etc. before the end of 1995.

ii) Those relating to other policies and therefore more difficult to implement e.g. changes in agricultural practices, replacement of pesticides and sewage sludge disposal regulations.

iii) Those of a general nature e.g. use of financial and economic instruments, the strengthening of public awareness and research.

Measures to rehabilitate the most critically polluted or over exploited groundwater resources should be put in train before the year 2,000 as part of a developing framework for the 21st century.

As a consequence it will be necessary for those working in the environmental field to broaden their approach to the development and maintaining of regional water supply schemes, wastewater treatment, sewage sludge disposal, agricultural practices etc. to ensure a genuine integration of water policies into those concerning human activities.

Two further developments in other EC countries could have major implications for water supplies in this country.

At present the use of polyelectrolytes as a coagulant aid in clarification is not permitted in France and the allowable monomer concentration in drinking water has in the past few years been halved in the U.K. In the event of the EC deciding to ban the use of polyelectrolytes in water treatment in the future, it would have major implications for the majority of water treatment plants in this country and others where the design of clarifiers has generally been based on relatively high surface loadings using polyelectrolyte as a coagulant aid.

The second development which could have widespread effects in this country, is a trend in Europe of substitution of chlorination due to the risks of trihalomethanes (THM's) and other chlorination byproducts (CBP's).

Multi-stage ozonation is becoming increasingly common in new plants in the U.K. and Europe while chloramination is also being considered.

Finally, a recent development in Sweden now being used also in Czechoslovakia is a novel approach to treating groundwater with high iron and manganese levels. The method requires the drilling of a series of injection wells into the aquifer around the production well.

Oxygen enriched water is then pumped down the wells into the water bearing layer, stimulating the activity of naturally occurring bacteria in a zone around the production well. The bacteria then precipitate out the iron and manganese which filter the groundwater as it passes through the zone to the production well. On one installation a manganese level of 1.2 mg/l has been reduced to a level less than the MAC value of 0.05 mg/l. Pilot schemes are also being established to assess the method's effectiveness in dealing with contaminated groundwaters. While it is as yet too early to assess the longer term effects on water quality it is certainly a development worth monitoring.

In conclusion, it is clear that changes in the approach to water supply will continue to occur at an even faster rate than in the past. The onus is on all of us to keep abreast of changes, to adapt these where appropriate to the Irish situation and to ensure that drinking water supplied to the consumer is at all times of the highest quality.

THE STATUS AND POTENTIAL

OF

LARGE GROUND WATER ABSTRACTIONS

Don O'Sullivan B.E. C.Eng. F.I.E.I. M.I.W.E.M.

THE STATUS AND POTENTIAL OF LARGE GROUND WATER ABSTRACTIONS

INTRODUCTION

In recent years the Department of the Environment has reviewed the position with respect to Sanitary Services and Environmental matters. The 1990 Environment Action Programme covers wide ranging proposals for sanitary services and environmental protection. In Co. Wexford we have carried out assessments and prepared designs for many capital water and sewerage schemes, for the coming 25 year period.

Designs have been progressed on four large regional water schemes and sources have been identified for the major portion of supplies for the design period of 25 years. Groundwater will play a major part and will, on completion of the schemes, provide up to 50% of Co. Wexford's drinking water supply.

EXISTING SYSTEM

Wexford Co. Council currently supplies 42,720 cu.m per day of drinking water, see table 1. Sixty eight percent of the population of Wexford (102,152) have public supply. Approximately thirty per cent have private supply much of which is supplied by group schemes. Many of these group schemes are supplied by Wexford Co. Council.

Water demand has increased sharply over the design life of the present schemes. As a result many schemes have inadequately sized mains, insufficient storage and insufficient water to meet consumer needs. In some schemes the Council have difficulty in meeting the current demand requirements, especially in the summer months and little protection is afforded the consumer in the event of a major breakdown. Running costs are high due to the condition and low capacity of the schemes.

In the late seventies and early eighties source development evolved from the major surface water sources to groundwater, because of its excellent quality it could, in many cases, be brought on stream to augment existing schemes without treatment.

Groundwater development evolved in a fragmented manner as the needs expanded. The rapid increase in demand at that time arose from a general increase in public supply brought about by group schemes, an increase in agricultural activity and an increase in tourism demands in coastal areas. Short-term demands were quickly met by direct abstraction from the South Wexford Limestone Aquifer and the Ordovician Volcanics at Coolgreany, Barnadown, Enniscorthy, Camolin and Carrickbyrne.

Groundwater presently supplies 35.3% of public supply in Wexford, supplying 15,089 cu m /day.

This water has been brought into supply at a fraction of the cost of surface water regional schemes augmentations. This development has not, however, been accompanied by the necessary infrastructure of collection and trunk mains, treatment and pumping infrastructure and storage reservoirs. This is very evident in the high cost of our capital programme for the period to 2016, which I will now discuss.

PROPOSED SYSTEM

The Council has defined a framework of six regional schemes for Co. Wexford to meet public water supply needs to the year 2016. The boundaries of the schemes titled East Central R.W.S., Fardystown R.W.S., South Western R.W.S., West Central R.W.S., North Central R.W.S., and Gorey R.W.S., are shown in figure No. 1.

The projected population, projected demands and estimated scheme costs are shown on table No. 2. The future demand in the year 2016 is estimated at 110,780 cu m/day and the estimated cost is £102.5 million. The projected demand shows an increase from the present public supply figure of 42,720 m^3/day to 110,780 m^3/day. This demand projection is not due to a population increase as population trends show a slight decrease. The principal reasons for the increase are:

- increased demand from agriculture as regional schemes are expanded.

- significant increase in projected tourism demands.

* increase in domestic water consumption and additional consumers as supplies are provided in adequate quantity and quality.

* specific provision for industry to permit industrial development.

Further analysis of the six regional schemes shows that groundwater will supply 49% of the projected demand. Table 2 details the raw water sources for the proposed schemes. The major groundwater sources proposed to meet projected demands on three regional schemes are shown on Table 4. Source locations are shown on figure 2.

Table 4

South Wexford Limestone Aquifer	Fardystown R.W.S.	26,390 m^3/day
Ordovician Volcanic Aquifer at Camross' Adamstown	West Central R.W.S.	11,700 m^3/day
Ordovician Volcanic Aquifer at Clogh, Barnadown- Essex Bridge	Gorey R.W.S.	14,100 m^3/day

The current status of these three groundwater schemes is :

*	Fardystown R.W.S. :	Sources proven, preliminary works complete; initial contracts underway, awaiting E.I.A. approval.
*	West Central R.W.S.:	Ground water source proven in 1987. Potential yield is estimated at 13,600 cu m/day. The Council propose to prepare a preliminary report for a Regional Water Scheme in the near future.
*	Gorey R.W.S. :	Ground water investigations are currently proceeding. The present estimate of proven groundwater is 6,000 cu m/day. A preliminary report is currently under preparation.

Typical chemical analysis of the three major groundwater scheme sources is shown on Table 5. As can be seen the limestone aquifer has hard water with high levels of iron and manganese. The volcanic aquifer shows high quality water. Nitrate leaching is not a problem. On quality grounds it is clear that these sources are very suitable for large abstractions serving regional schemes.

LARGE GROUND WATER ABSTRACTIONS FOR REGIONAL SCHEMES

The principal requirements of a regional water scheme are :

- an integrated scheme with raw water collected and brought to a single central treatment plant.

- the provision of trunk mains to transport water and storage on the basis of 24 hours primary storage and 24 hours secondary storage.

- the provision of a microprocessor based telemetry system for scheme control and management.

When groundwater is proposed to supply a regional scheme, the following points should be considered :

- a wellfield of sufficient yield to meet scheme demands is needed, located a reasonable distance from the main demand centre.

- It is desirable that the wellfield be confined to an area of reasonable size to enable cost effective collection.

- treatment to meet E.C. (Quality of Water for Human Consumption) Regulations 1988 must be feasible and economic.

- ground water protection must be assured and saline intrusion must be controlled.

The Wexford groundwater schemes will operate within these guidelines. Two wellfields, the north and mid wellfields will supply the Fardystown Scheme, a wellfield from Carrickbyrne Hill to Adamstown will supply the West Central Scheme and a wellfield central on Barnadown will supply the Gorey Regional Scheme. A typical wellfield would have 10 to 15 boreholes 400m to 600m apart and each producing in the range 900 to 2000 cu m/day. Boreholes would be drilled to a depth of 90m and finished to an internal diameter of 250 mm. Boreholes would be lined in rock with a thermoplastic well liner of I.D. 250mm and complementary screen.

I will now outline in greater detail the proposed Fardystown R.W.S. and the proposed Gorey R.W.S.

FARDYSTOWN R.W.S.

The proposed scheme will serve an area of 23450 hectares to the south east, south and south west of Wexford Municipal Borough; in addition it will augment the Wexford Municipal Borough supply with 9090 cu m/day, and the total scheme supply is 26,390 cu m/day for the design year 2011. This demand will be supplied by twenty boreholes located in the north and mid wellfields. See Figure No. 3.

Prior to the 70's most of the rural area was supplied by the Taylorstown treatment works from the Owenduff River source. In the 70's the demand increased due to the completion of group schemes and increased agricultural requirements. The Taylorstown scheme was no longer adequate and the Council drilled boreholes at Busherstown and Fardystown which yielded 1300 cu m/day. Between 1979 and 1981 the Council drilled several boreholes north of this region under the supervision of Mr. K. Cullen, Consulting Hydrogeologist. Significant yields were encountered and in the intervening period the system has been heavily dependant on this water. At present the boreholes from this aquifer supply 8,180 cu m/day to the region. This supply is, however, brought onstream by random pumping into service mains with the result that wide fluctuation in pressures occur. The system is manually controlled and has inadequate storage and inadequate pipe network. Departures under the E.C. (Quality of Water for Human Consumption) Regulations 1988 have been obtained for iron and manganese. Chlorination and fluoridation have not been provided and the water is hard. However, there are no difficulties in meeting bacteriological standards.

In 1984 Wexford Co. Council commissioned P.H. McCarthy Son & Partners to prepare a preliminary report on the supply for the region based on groundwater. The report, completed in 1985, recommended a regional scheme based at Fardystown, where treatment for iron and manganese chlorination and fluoridation would be provided. Softening of water was not recommended due to high capital and operating costs; however, provision would be made for future softening plant. The report recommended a programme of exploratory drilling to prove 12,000 cu m/day of groundwater along a line from Walshestown to Bridgetown. In addition the report recommended a pilot study using a pilot treatment plant for the removal of iron and manganese. The projected demand for the area was assessed at 16,592 cu m by the design year. The area would be served by seven supply zones.

Following approval to the report by the Department of the Environment in July 1986, contracts were put in hand for the drilling and testing of boreholes and the pilot study.

During the spring/summer of 1987 14 trial boreholes were drilled and tested in the South Wexford Aquifer along a line from Walshestown-Mayglass-Bridgetown. It was concluded that twelve of the sites were capable of delivering the entire 16,600 cu m/day (see Table 6). Chemical analysis (see Table No. 7) showed high iron and manganese levels, high hardness and no bacteriological contamination, as the low total coliform counts were later discounted following clear results from fresh samples. The levels of iron and manganese at Busherstown No. 1 borehole were 0.15 mg/l iron and 0.25 mg/l manganese. These levels were close to the expected averge levels and accordingly, the pilot study was carried out on this water. A pilot treatment plant supplied and commissioned by Harper & Fey Ltd. was operated from September 1987 to February 1988. From the trials two successful methods of iron and manganese removal were identified. These were :

* filtration using a 400mm layer of manganese dioxide media on standard rapid gravity filter construction with physical aeration;

* filtration using a 700mm layer of Relite M-50 media on standard rapid gravity filter construction with oxidation using potassium permanganate.

The manganese dioxide option was considerably cheaper.

Table No. 8 shows the capital and running costs of each method for a scheme supply of 16,600 cu m/day as outlined in "EngineersReport on Testing Programme" by P.H. McCarthy Son & Partners 1988.

At this time (in early 1988) Wexford Co. Council considered the needs outlined in the study of 1980 on behalf of Wexford Borough Corporation by J. B. Barry & Partners, Consulting Engineers. Preliminary investigations by P. H. McCarthy Son & Partners concluded that augmenting the Wexford Borough from the Fardystown Scheme was viable from a cost point of view. It was also concluded that there was sufficient groundwater proven to base a revised enlarged Fardystown Scheme supplying 26,390 cu m/day. The Council instructed P. H. McCarthy Son & Partners to prepare a Supplementary Report which would review the initial scheme and provide for Wexford Municipal Borough a supply of 9090 cu m/day. This report was completed in Nov. 1988 and recommended a total supply from the aquifer of 26,400 cu m/day from twenty boreholes. It was proposed to meet the additional demand by further development of existing boreholes at Rathmacknee, Ballyfinoge, Ballykelly, Rowestown and Sinnottstown, which had been pumped to supply over the years. These boreholes would form the North Wellfield and the boreholes along the line from Walshestown-Mayglass-Bridgetown would form the mid wellfield. The report recommended that the treatment works site be relocated at the epicentre of the groundwater sources at Mayglass. Collection mains would comprise two manifold type mains. The design of the collecting system involved the use of soft start variable speed pumps and telemetry controlled cut-in and shut down arrangements for the borehole installations. The system was designed to cover the full range of operating pressures. Surge pressures were assessed by using a computer model and K9 ductile iron pipes with non return valves at each borehole were recommended. The pipe network and storage system are based on eight supply zones. 26,400 cu m of treated water would be stored at the works site at Mayglass. A 60 metre high tower would be located at this site and 26,400 cu m of secondary storage would be located within the supply regions. A comprehensive microprocessor based telementry system has been proposed for scheme management.

To date, contract works have been completed on pipelines from Ashfield Cross to Rosslare Harbour and contract works are underway on reservoirs at Rosslare Harbour and Staplestown and a water tower at Rosslare Harbour.

In June 1990 Wexford Co. Council submitted an Environmental Impact Statement to the Minister for the Environment under the E.C. (Environmental Impact Assessment) Regulations 1989. This study was required because the proposal involves "the drilling for water supplies where expected supply would exceed 5000 cu m per day." We are awaiting the Minister's Certificate of approval.

The E.I.S. prepared by P. H. McCarthy Son & Partners showed that the impact of the abstraction of 26,390 cu m/day from a groundwater point of view will result in :

* a drawdown of 20 to 30 m at the individual boreholes which will reduce to 2 - 3 m at 1 kilometre away.

- the groundwater level lowering will result in a landward movement of the saline/fresh water interface by 100m to 500m.
- the existing spring flows and river base flows will be reduced and the risk of induced sink-holes is increased.

In order to minimise the risks the borehole sites have been chosen so as to spread the drawdown over a larger area and six observation boreholes will be sited to the South and East of the aquifer for monitoring ground water levels. The Council propose to provide an alternative supply where private boreholes dry up as a result of the lowering of the groundwater table.

Having regard to the major benefits of abstracting such a large volume of groundwater these impacts are considered minimal.

The present estimate of the total scheme cost is **£21.5m.**

GOREY REGIONAL W.S.

The boundaries of the proposed scheme define the area from the County boundary to the north to Ballygarrett to the south and from the coast to a north south line running seven kilometres west of Gorey Town (See Fig. No. 4).

The principal demand areas include Gorey Town and Environs, Courtown/Riverchapel, Coolgreany, Camolin and Ballycanew. The projected population in the design year of 2016 is 12,900 persons.

The existing Gorey-Courtown scheme was constructed in the late 1960's and served Gorey Courtown, Riverchapel, Ballycanew and the rural area south to Cahore. The scheme currently involves the abstraction of 2730 cu m/day from the River Bann at Pallas and Kilmichael and treatment using slow sand filtration at Creagh. The water quality is A2 as defined in the E.C.(Surface Water Abstracted for Drinking Water) Regulations 1989 and accordingly the treatment plant does not produce water to the standard of the E.C. (Quality of Water for Human Consumption) Regulations 1988. In particular high colour and ammonium in times of high river flows cannot be removed. In the late seventies the scheme became severely overtaxed due to the increased agricultural and tourism demands.

However, as the low flows in the River Bann would not be sufficient to sustain a regional water scheme without impoundment, the Council considered an impoundment scheme at Pallas. Geological investigations carried out in 1978 and 1979 showed that dam construction would be difficult and expensive. The Council turned its attention to groundwater and proceeded with a ground water investigation in 1981 under the supervision of Mr. K. Cullen, Consulting Hydrogeologist.

A productive aquifer was developed around Barnadown and at present two borehole sources yielding 2730 m^3/day have been commissioned. The Gorey-Courtown scheme has now been subdivided and the groundwater scheme serves the southern half. The present schemes are now overtaxed and the schemes cannot meet current demand requirements, particularly in the Summer season.

In September 1991 Wexford Co. Council appointed P. H. McCarthySon & Partners to prepare a preliminary report to prepare a regional water scheme based on development of further groundwater resources, centralised treatment and storage. K. Cullen & Co. Ltd., Consulting Hydrogeologist, was appointed to advise and supervise the groundwater investigation. Preliminary drilling was carried out in February and March 1992. Results now indicate that a major wellfield can be developed in the Volcanic Aquifer at Clogh-Barnadown-Essex Bridge. Water quality from results to date indicate that no treatment except chlorination and fluoridation will be required.

Yields to date indicate that 6,000 cu m/day could be supplied from this wellfield - see Table No. 9. While we hope that the projected demand figure of 14,100 cu m/day can be supplied by this wellfield, other options may have to be considered. These include:

- continued abstraction from the River Bann, but with a new physio-chemical treatment works at Creagh;
- dispersed groundwater sources serving specific areas not integrated into the major scheme e.g. Coolgreaney Region.

However, a major integrated scheme centred on Barnadown which is central to demand areas would mean significant benefits in capital and running costs over these two options. There can be no doubt that the full development of the wellfield at Clogh-Barnadown-Essex Bridge will be of significant economic benefit compared to the impoundment scheme on the River Bann, where the estimated scheme cost is likely to be double the ground water option.

In the development of the Clogh-Barnadown-Essex Bridge wellfield we propose to provide boreholes drilled to a depth of 90m and finished to an internal diameter of 250mm. A collection main will transport water to a central pumping and dosing station where the water will be pumped to a primary storage location. The full scheme details can only be finalised when the aquifer has been fully tested and proven. We propose to provide observation wells east of the aquifer to monitor the locations of the saline/fresh water interface. It is our intention to prepare a full groundwater model to determine the relationship between the water table, the rate of abstraction and the saline/fresh water interface. This model will assist in the preparation of the Environmental Impact Statement and will be subsequently developed as further data on river flows and groundwater is collected.

PROTECTION POLICY

Mr. Kevin Cullen, Consulting Hydrogeologist was commisioned in 1987 to prepare a report on Aquifer Protection. The Council subsequently implemented a ground water protection policy based on source protection. The policy is operated by the Planning section of Wexford Co. Council, and will be incorporated in the 1992 review of the County Development Plan.

LEGAL ASPECTS OF MAJOR ABSTRACTIONS

Development of groundwater in Ireland is still in the early stages of development. Aquifers are rarely pumped beyond their capacity. There are, however, legal difficulties which need to be addressed. I consider that there is a need for legislation wherby Local Authorities can in the public interest control the abstraction of groundwater. Provision could be made for licensing of groundwater abstraction similar to the Water Resources Act of 1963 in Britain. Exemption could be permitted in the case of small abstractions, e.g. for domestic purposes. In Ireland Local Authorities presently use the Planning Acts for new developments, but I consider that a licensing system would ensure satisfactory control of all abstractions.

The application of the Water Supplies Act 1942 to groundwater, whereby a Local Authority must prepare a proposal etc. has been raised by lawyers on behalf of objectors in recent times. We have taken the view that "Source of Water" which is defined to mean "any lake, river, stream, well or spring" does not cover an aquifer. Compensation under this Act would not then apply to groundwater abstractions.

FINANCING REGIONAL SCHEMES

As I have outlined, the investment needs for water supply in Co. Wexford is estimated at £102.5 million in 1991. Estimate of immediate investment needs in the country as a whole are considered to be of the order of £1500 million for public water supply. The Environment Action Programme published by the Department of the Environment indicates funding on drinking water in the 10 year period to the year 2000 to be £300 million, i.e. £30 million per year. It is clear from this that the needs will not be met unless increased funding is provided.

CONCLUSION

In conclusion I would say that large groundwater abstractions have a major part to play in the provision of public water supplies. They must be considered as an option when designing large regional water supply schemes. As I have outlined, groundwater provides the most economic and cost effective solution to water supply in 50% of the public supply in Co. Wexford. It is clear that resources and time must be provided to prove the sources in advance of framing the scheme. One disadvantage in this is that Local Authorities must carry the cost of this preliminary works for a long period. This, however, is something which could be easily addressed. It is necessary that major groundwater abstraction be accompanied by an aquifer protection regime and as aquifers develop by groundwater modelling to assist in understanding the flow through the aquifer and to manage further development of the aquifer. I have also indicated the need to review the law relating to groundwater abstractions and to examine the needs for funding our major regional schemes.

REFERENCES

Callery P. (1988) "Groundwater for Public Supply"

Cullen K.T. (1987) "Fardystown Regional Water Supply Scheme" Trial Well Drilling and Testing Programme

Cullen K.T. (1987) "Camross-Adamstown Regional Water Supply Scheme" Groundwater Investigation.

Cullen K.T. (1987) Aquifer Protection Policy - A Discussion Document.

P.H.McCarthy Son & Partners (1985) - Preliminary Report Fardystown Regional Water Supply Scheme

P.H.McCarthy Son & Partners (1988) - Supplementary Report Fardystown Regional Water Supply Scheme

P.H.McCarthy Son & Partners (1990) - Environmental Impact Study Fardystown Regional Water Supply Scheme

Environmental Research Unit (1991) - Water Supply and Sewerage Needs Study - Report on Co. Wexford

Hore T.E. (1991) The Development and Protection of Ground Water in Co. Wexford.

TABLE 1

WATER SUPPLY SCHEMES IN CO. WEXFORD

Surface Water Abstractions

		Vol Cu m/day
South Regional	W.S.S.	6363
Sow Regional	W.S.S.	2954
Enniscorthy	W.S.S.	3180
Gorey Regional	W.S.S.	2730
Ferns	W.S.S.	454
Bunclody	W.S.S.	454
Wexford Town	W.S.S.	8180
New Ross	W.S.S.	3180
Taghmon	W.S.S.	136
Subtotal		27,631

Groundwater Abstraction

South Regional	W.S.S.	8180
Sow Regional	W.S.S.	227
Enniscorthy	W.S.S.	909
Clogh Regional	W.S.S.	2727
Coolgreany	W.S.S.	909
Kilmuckridge	W.S.S.	682
Bunclody	W.S.S.	273
Carrickbyrne	W.S.S.	364
Clonroche	W.S.S.	273
Miscellaneous		545
Subtotal		15,089
TOTAL :		42,720

TABLE 2

Scheme	Population Served		Future Demand cu m/d(2016)	Costs (Est. (2016)
	now	Future(2011)		
1. East Central	12,045	11,185	15,800	£18.5m
2. Fardystown				
(a) Rural	11,523	10,789	17,300)	£24.0m
(b) Wexford Borough & Environs	15,365	17,511	17,262)	
3. South Western Regional W.S.	9,099	8,411	14,418	£11.0m
4. West Central				
(a) Rural	9,476	8,683	6,800)	£16.0m (Est.)
(b) New Ross & Env.	6,216	7,167	6,800)	
(c) Rathnure/ Ballywilliam	3,207	2,902	3,500)	
5. North Central				
(a) Rural	12,615	11,667	8,000)	£18.0m (Est.)
(b) Enniscorthy UDC & Env.	7,753	8,939	6,800)	
6. Gorey Regional	13,506	12,868	14,100	£15.0m (Est.)
Excluded upland regions	1,347	1,219		
TOTAL :	102,152	101,341	110,780	£102.5m

Pop figures based on 1986 Census

TABLE 3

PROPOSED SCHEME SOURCES - YEAR 2016 A.D.

Scheme	Demand m^3/d (year 2016)	Surface Water River Source cu m/d	Groundwater Aquifer cu m/d
1. East Central RWS	15,800	15,800 Boro	-
2. Fardystown RWS			
(a) Rural	17,300	-	17,300) Carb.
(b) Wexford M.D.	17,262	8,172 Sow Coolree	9,090) Limestone
3. South Western RWS	14,418	14,418 Owenduff Corock	-
4. West Central RWS			
(a) Rural	6,800	-	6,800)
(b) New Ross/Env	6,800	3,400 Poulmonty Dranagh	3,400) Ordovician) Volcanic
(c) Rathnure/ Ballywilliam	3,500	2,000 Boro	1,500)
5. North Central RWS		Urrin	
(a) Rural	8,000	7,000 Curralane Clody	1,000)) Ordovician
(b) Enniscorthy & Environs.	6,800	5,800 Slaney	) Volcanic 1,000)
6. Gorey Regional WS	14,100		14,100 Ordovician Volcanic
TOTAL :	**110,780**	**56,590**	**54,190 (49%)**

Major Groundwater Schemes :

1.	Fardystown R.W.S.	26,390 cu m/d	Carboniferous Limestone
2.	West Central R.W.S.	11,700 cu m/d	Ordovician Volcanic/Camross
3.	Gorey R.W.S.	14,100 cu m/d	Ordovician Volcanic/Clogh

TABLE 5

WEXFORD COUNTY COUNCIL

TYPICAL CHEMICAL ANALYSES OF MAJOR AQUIFERS

PARAMETER	UNIT		Fardystown Scheme Borehole No.1	Camross/ Adamstown Scheme Borehole Nos 35-7	Gorey Regional W.S.S. Barnadown No. 1	EC (Drinking Water) Regulations 1988 M.A.C. Value
Calcium	Ca	mg/l	85	20.4	31.2	200
Magnesium	mg	mg/l	21	7.3	7.8	50
Sodium	Na	mg/l	22.4	15.	4.0	150
Potassium	K	mg/l	2.4	1.3	1.40	12
Bicarbonate	HCO_3	mg/l	354.	70.7	107.3	-
Sulphate	SO^4	mg/l	7.	9.5	6.50	250
Chloride	Cl	mg/l	36.	26.0	21.0	250
Ammonium	NH_4	mg/l	0.01	0.1	0.05	0.30
Nitrate	N	mg/l	<0.10	0.7	2.6	11.3(50mg/l NO_3)
Zinc	Zn	mg/l	0.03	N.E.	0.03	1.0
Copper	Cu	mg/l	<0.03	<0.04	N.D.	0.5
Iron	Fc	mg/l	0.50	<0.05	0.0	0.2
Manganese	Mn	mg/l	0.24	<0.02	0.0	0.05
Lead	Pb	mg/l	<0.01	N.E.	N.E.	0.05
Fluoride	F	mg/l	0.12	N.E.	N.D.	0.8 to 1.0
Carbon Dioxide	CO_2	mg/l	N.E.	N.E.	N.E.	-
O-Phosphate	P	mg/l	0.01	N.E.	N.E.	-
pH	Units		7.7	6.7	6.95	6.0 - 9.0
Hardness	$CaCO_3$		300.	81.	110.	-

Table 5 Contd.

PARAMETER	UNIT	Fardystown Scheme Borehole No.1	Camross/ Adamstown Scheme Borehole Nos 35-7	Gorey Regional W.S.S. Barnadown No. 1	EC (Drinking Water) Regulations 1988 M.A.C. Value
T.D.S.	mg/l	372.	130.	N.E.	1000
Colour	HAZEN	<5.	5.	0	20
Turbidity	N.T.U.	1.7	0.4	N.E.	10
Conductivity	μS/cm	685.	220.	293.	1500
Alkalinity	$CaCO_3$ mg/l	292	58.	88.	-
Coliforms	MPN/100ml	0.	0.	N.E.	<1
E.Coli	MPN/100ml	0.	0.	N.E.	<1
Temperature	°C	N.E.	N.E.	11°	25

N.E. - Not Examined N.D. - Not Determined

TABLE 6

WEXFORD COUNTY COUNCIL

SCHEDULE OF PROPOSED PRODUCTION BOREHOLES

SCHEME	BOREHOLE NAME/NO.	BOREHOLE LOCATION	ESTIMATED YIELD M^3 / day
Fardystown Regional Water Supply Scheme	T.W. No.1	Walshestown	1354
	T.W. No.2	Walshestown	1700
(Carboniferous Limestone Aquifer)	T.W. No.3	Walshestown	1745
	T.W. No.4	Mount Pleasant	1670
	T.W. No.5	Hardyregan	1286
	T.W. No.6	Churchlands	1110
	T.W. No.7	Mayglass	2061
	T.W. No.8	Busherstown	1505
	T.W. No.9	Harpoonstown	1090
	T.W. No.10	Mulrankin	1675
	T.W. No.11	Mulrankin	1952
	T.W. No.13	Mountcross	1090

MID WELLFIELD TRIAL BOREHOLE QUALITY DATA

PARAMETER	UNIT	TRIAL WELL NO											
		1	2	3	4	5	6	7	8	9	10	11	13
Calcium	Ca mg/l	85	22	25	96	66	72	70	56	77	77	63	82
Magnesium	mg mg/l	21	22	20	19	16	18	21	22	23	21	24	13
Sodium	Na mg/l	22.4	22.2	20	20	20	27.5	23.5	31.5	31.5	33	20	27
Potassium	K mg/l	2.4	2	2	3.4	1.6	1.9	2.5	2.2	2.3	1.2	1.4	1.8
Bicarbonate	HCo3 mg/l	354	165	165	382	259	303	297	273	348	329	309	264
Sulphate	SO4 mg/l	7	8	7.5	9	12.5	10.5	18.5	6.5	11	6	5	19.5
Chloride	Cl/mg/l	36	36	33	30	27	32	36	42	48	55	53	52
Ammonium	NH4 mg/l	0.01	0.04	0.06	0.01	0.01	0.03	0.03	0.01	0.04	0.06	0.01	0.01
Nitrate	NO3 mg/l	<0.44	0.44	0.44	1.33	<0.44	<0.44	<0.44	<0.44	<0.44	<0.44	<0.44	21.28
Zinc	Zn mg/l	0.03	0.02	0.02	0.02	0.01	0.01	0.08	0.01	0.04	0.03	0.02	0.03
Copper	Cu mg/l	<0.03	<0.03	0.04	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Iron	Fe mg/l	0.5	<0.05	0.34	<0.05	0.07	0.35	0.25	0.12	<0.05	0.1	0.27	0.2
Manganese	Mn mg/l	0.24	0.11	0.11	0.17	0.14	0.11	0.44	0.07	0.18	0.04	0.21	<0.02
Lead	Pb mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoride	F mg/l	0.12	0.09	0.11	0.09	0.09	0.12	0.1	0.6	0.7	0.09	0.08	0.07
Carbon Dioxide	CO2 mg/l	N.E.	N.E.	12	18.3	14.5	14.0	13.5	14.5	14.5	14.3	13.3	14.0
O-Phosphate	P mg/l	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
pH	Units	7.7	7.4	7.6	7.6	8.1	8.0	7.7	7.9	7.7	7.7	7.7	7.7
Hardness	CaCO3 mg/l	300	146	144	320	228	254	260	230	288	274	258	260
T.D.S.	mg/l	372	210	218	381	295	332	332	311	382	367	342	345
Colour	Hazen	<5	10	10	<5	<5	<5	<5	<5	<5	<5	<5	<5
Turbidity	N.T.U.	1.7	0.5	0.5	0.2	0.1	1.2	1.4	2.0	0.3	5	0.3	22.4
Conductivity	US/cm	685	391	380	700	514	624	612	595	710	692	645	663
Alkalinity	CaCO3 mg/l	292	136	136	316	216	254	246	226	288	272	256	218
Coliforms	MPN/100ml	0	0	2	5	1	-	0	5	6	0	2	4
E.Coli	MPN/100ml	0	0	0	0	0	0	0	0	0	0	0	0

Table 7

TABLE 8

FARDYSTOWN R.W.S.

IRON & MANGANESE REMOVAL - RELATIVE COSTS FOR SCHEME OF 16,600 cu m/day

	Manganese Dioxide	Relite M-50
Total Capital Cost	£480,000	£608,000
Total running cost/ annum	£2,265	£3,275

TABLE 9

BOREHOLE YIELDS - WELLFIELD - BARNADOWN-ESSEX BRIDGE-BANOGE

	Yield cu m/day	
Barnadown No. 1	1820	current abstraction
Barnadown No. 2	910	current abstraction
Money Cross	450	reserve abstraction
Banoge	910	estimated
Essex Bridge	1600	estimated
Carriganeagh	310	estimated
TOTAL :	6,000	

March '92

WATER SUPPLY AREAS WITH SCHEME WELLFIELD LOCATIONS

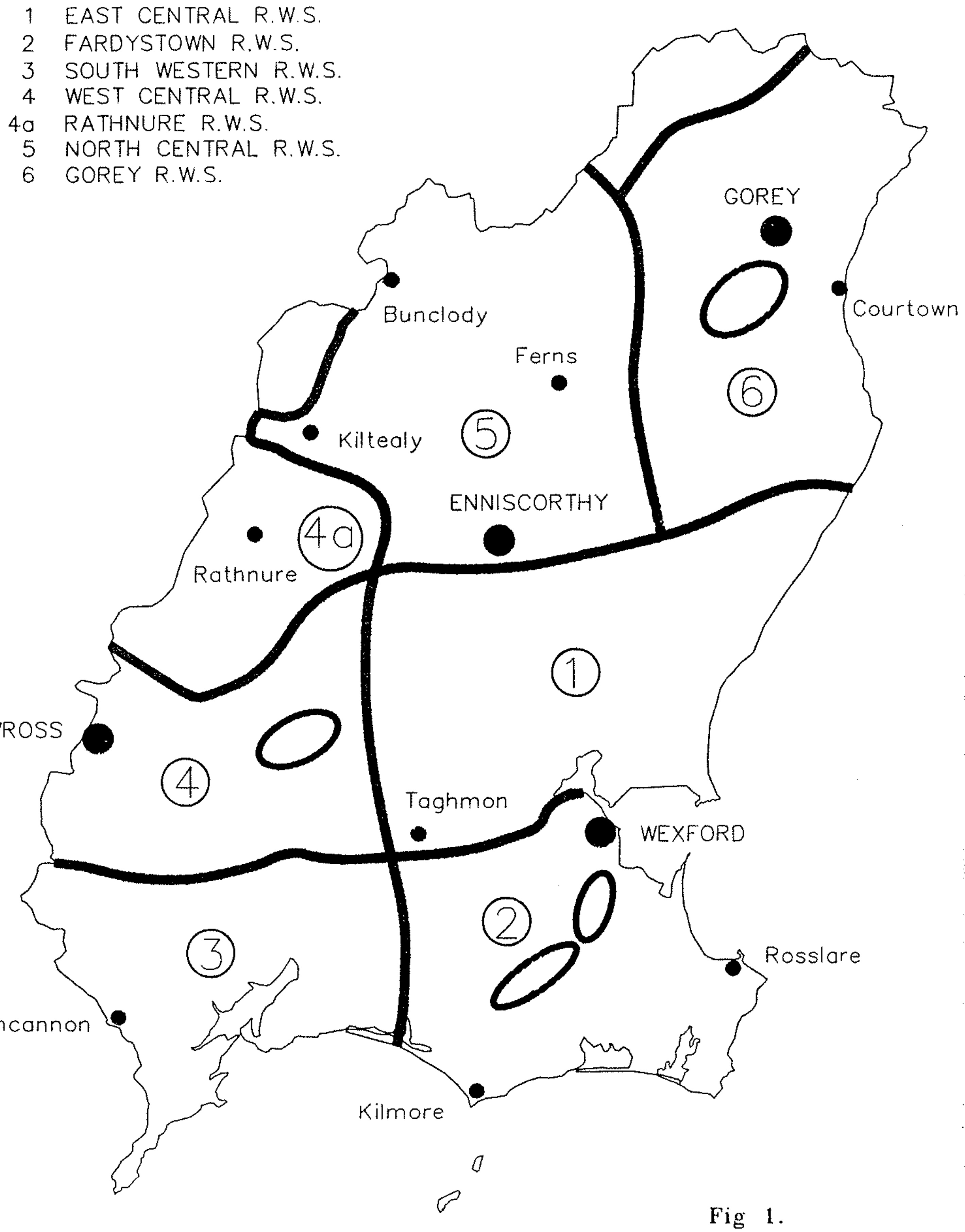


Fig 1.

SOLID GEOLOGY OF CO. WEXFORD WITH SCHEME WELLFIELD LOCATIONS

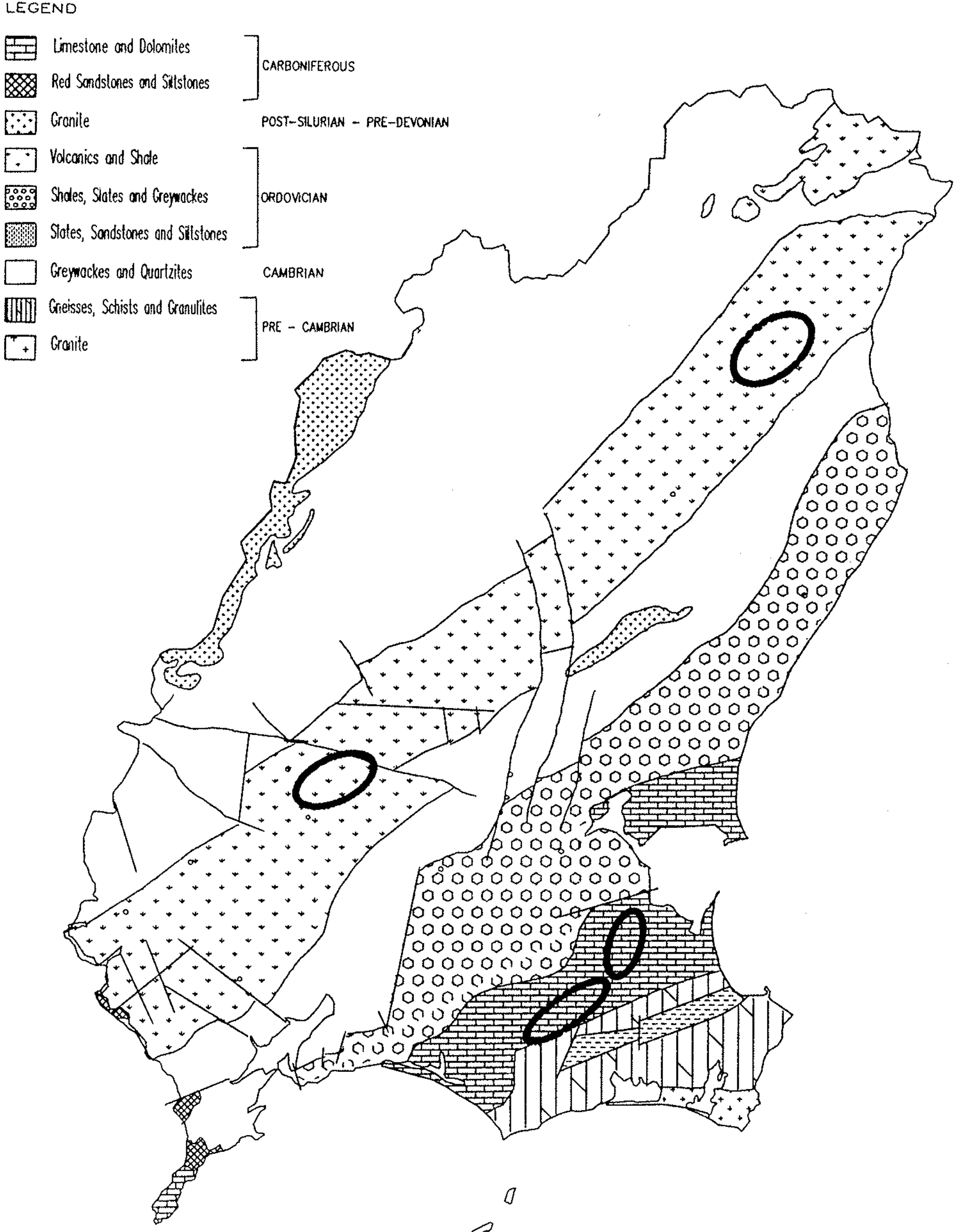


Fig. 2

FARDYSTOWN R.W.S.
WITH
WELLFIELD LOCATIONS

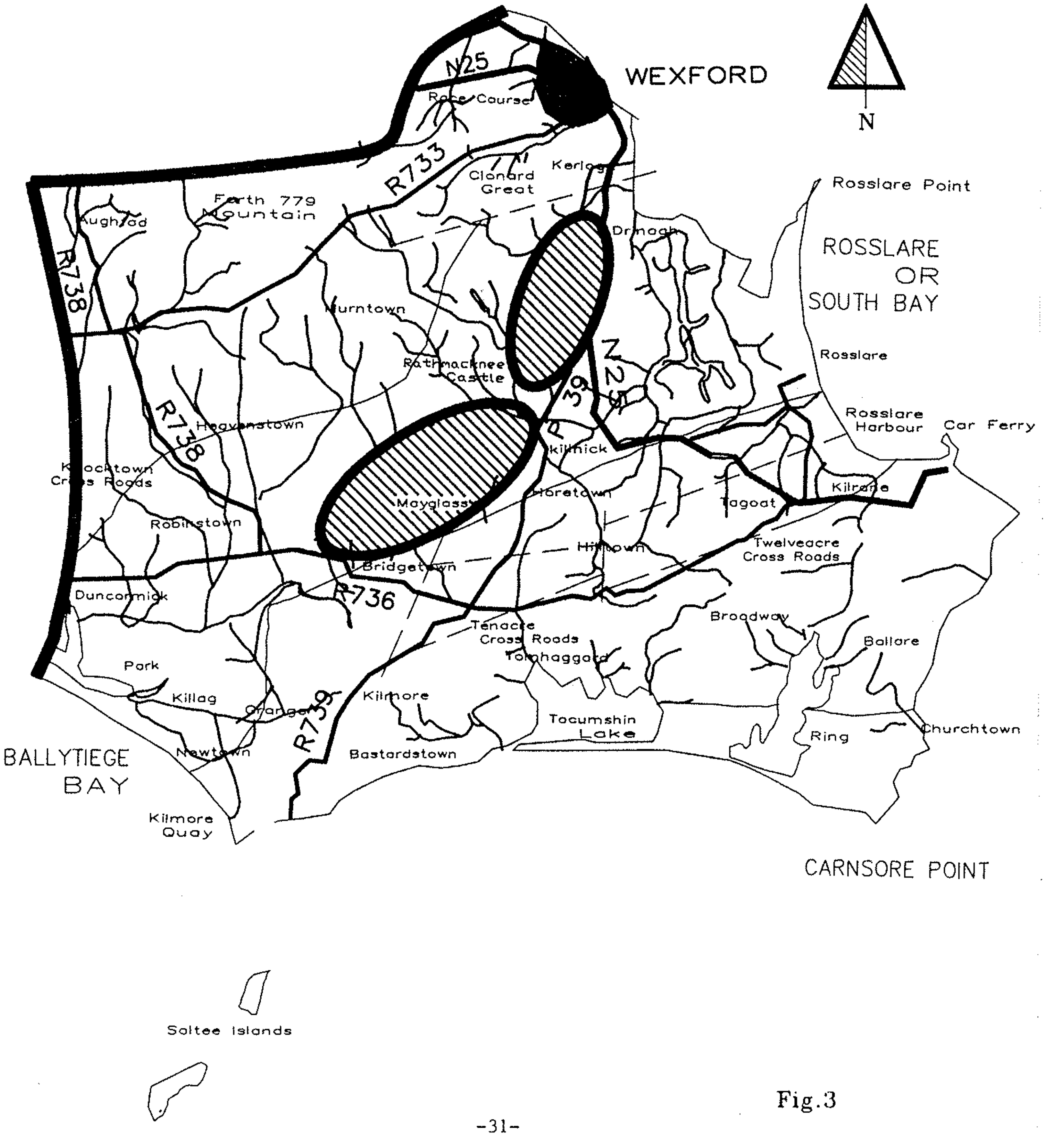


Fig.3

GOREY R.W.S.
WITH
WELLFIELD LOCATION

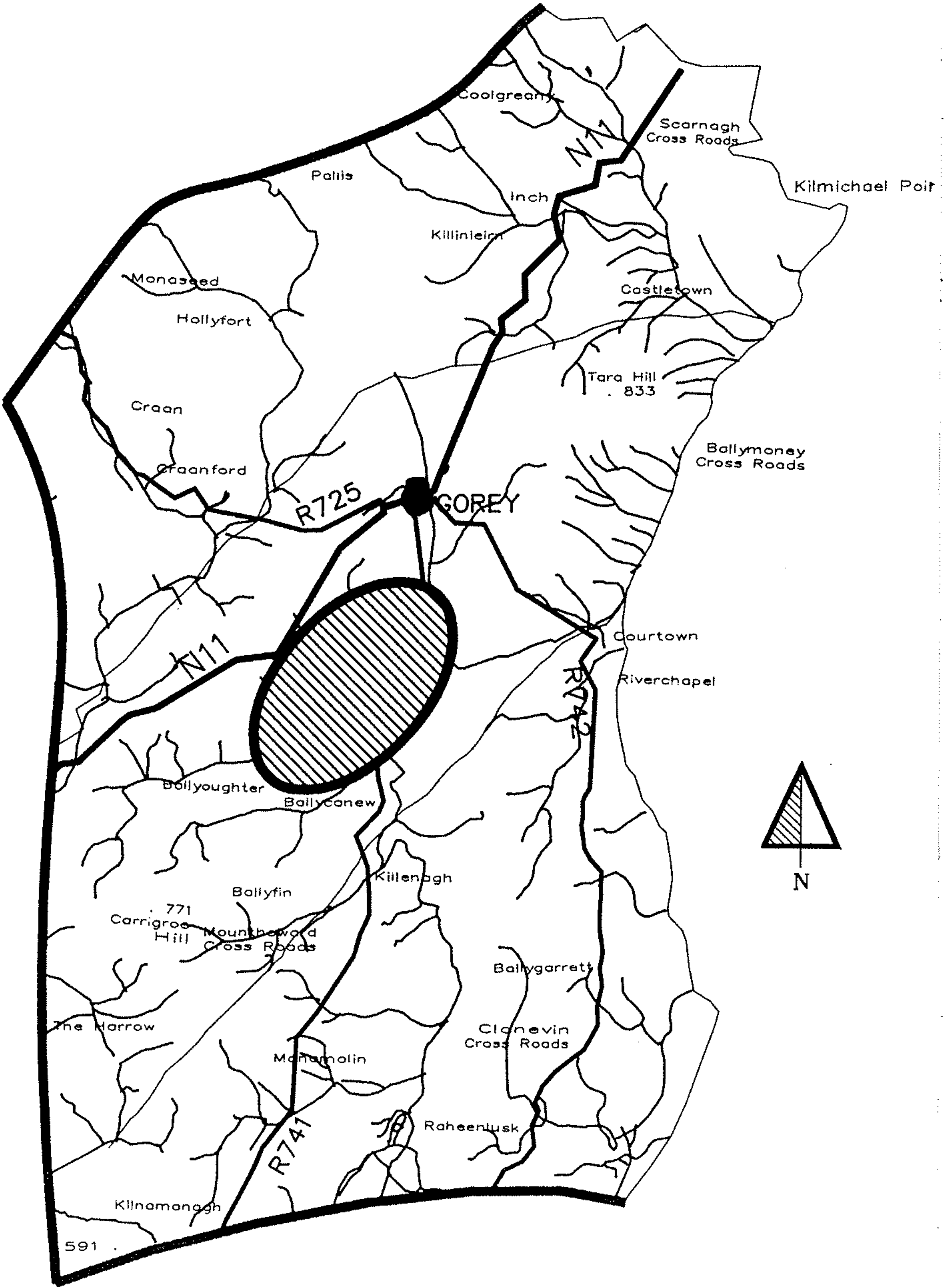


Fig. 4

12th ANNUAL IRISH IAH GROUNDWATER SEMINAR

APRIL 7TH AND 8TH, 1992.

THE GROUNDWATER RESOURCES OF IRELAND

C.R. ALDWELL, GEOLOGICAL SURVEY OF IRELAND.

Definitions of what may be described as groundwater resources vary. Rough estimates can be made of the global quantities of water contained in the ground based on porosity, permeability, land area and effective aquifer thickness. Another approach is to establish the annual water balance in which annual groundwater recharge = precipitation - run off and evapotranspiration. Clearly a number of constraints may reduce at a practical level the amounts of groundwater which can be economically taken for human use.

One important constraint is the permeability (transmissivity) of an aquifer. For major groundwater development it is necessary that large quantities of suitable quality water can move to and are available at a specific site. The groundwater contained in low permeability rocks with a large areal extent, is important for plant growth sustaining river flow, and private supplies but is not a readily extractable resource for major supplies.

For this reason the Geological Survey in estimating Irish groundwater resources restricts the calculation to the mean annual recharge of the relatively high permeability Irish aquifers. Such major aquifers underlie about one third of the land area of the Republic - i.e. 23000 km^2.

These are:

	Very approx areal extent (km^2)
Limestones	12,000
Quaternary sands and gravels	10,000
Old Red Sandstone	1,900
Volcanics	1,000
Other Sandstones	1,000

Table 1. The High Permeability Irish Aquifers

These figures add up to more than 23,000 km^2 since the Quaternary aquifers often overlie the older rocks. Almost all the consolidated rock aquifers depend on secondary permeability. This makes it difficult to assign areal extent to the proportion of limestone and ORS which should be classed as a major aquifer. Local conditions of geological structure are the deciding factors. In this paper about 40 per cent of the limestone and 15% of the near surface (top 100m) ORS has been designated a major aquifer.

Likewise the Quaternary aquifers in our present state of knowledge are difficult to quantify. An areal extent for sand, gravel and alluvium of about 15 per cent of the total land area is suggested.

Regional Trends

Since the limestone and Quaternary aquifers have much the greatest areal extent they are important sources of groundwater in most parts of the country (see Table 2). Limestone aquifers are of particular importance in most midland counties and in parts of other counties such as in Cork, Kerry and south Wexford (see Table 3). Quaternary aquifers are of major importance in eastern counties such as Wicklow, Kildare and Louth. Indeed it is only in the north Midlands and Waterford where sands and gravels have an insignificant role as aquifers.

The Old Red Sandstone has shown that it can be a highly productive aquifer in parts of Cork and Limerick and the Midlands. In this paper an attempt has been made to give more recognition to the ORS by extrapolation - especially in Kerry and Waterford. In these latter two counties however it likely to be high yielding only in local permeable zones.

The volcanic aquifers are mostly confined to Waterford, Wexford and south Wicklow. Volcanic rocks (Carboniferous) are also plentiful in Limerick but for the present have been included together with the limestones with which they are closely connected.

Other sandstones are those younger than the ORS, which are mostly Carboniferous in age and also the locally highly productive Kingscourt Permo-Triassic sandstones. Such sandstones contain over 60% of the estimated groundwater resources of Co. Donegal, and are important in Monaghan, Leitrim and Cavan.

County Resources

In Table 4 an attempt has been made to quantify the groundwater resources of each county. As can be seen the amounts range all the way from 5 Mgpd for a truncated Co. Dublin to 236 Mgpd for Co. Mayo. Obviously if a county is large, has a high rainfall and extensive permeable rocks there are likely to be large groundwater resources. On the other hand if a county is small, flat, located in the east and has mainly impermeable rocks there will be relatively little groundwater. Another factor that needs to be taken into account is the availability and accuracy of data. The South East and parts of the Midlands have been the areas most studied and therefore the figures for those counties are more reliable. The situation in the West is more uncertain. Practical consequences are that counties such as Mayo may have been assigned relatively too much and others, like Donegal too little. Whatever ultimately may be shown to be the case, clearly Ireland's groundwater resources are very large and in most counties vastly exceed current or foreseeable needs.

Constraints on Use of Groundwater Resources

In Table 4 there are estimations of county groundwater resources in terms of mean annual recharge to the major aquifers. Is all this water actually available for human use? It is not possible to provide a simple universally applicable answer to this question. The water is in fact through-put and circumstances vary from one county and one area to another. The answer will depend on such factors as the natural hydrogeological conditions, from where the water is being taken and what use is to be made of the abstracted water.

Let us consider for a few moments, some of the possible negative effects of large water abstractions. These effects include:

Reduction in spring and stream flow;
Interference with existing wells;
Land subsidence;
Change in water quality;
Sea water intrusion.

There are of course some potential positive effects. Winter flooding could be reduced in some districts by lowering the water-table and recharge might be increased.

If water is abstracted in the natural discharge zone of the aquifer the consequences will be different than when it is taken high up in the recharge zone.

Then what is going to happen to the abstracted water. How much of it will be returned to the hydrological system after use?

Clearly enough uncertainty exists to justify an EIS in the case of large groundwater abstractions whether it be for purposes of water use or dewatering for engineering or mineral extraction purposes.

Conclusions

In weighting the various pros and cons it is worth remembering that although the listed groundwater resources may seem very large in terms of Ireland's water use, in fact they are very cautious and conservative. The minor aquifers and non-aquifers contribute several times the quoted amounts in the main aquifers to stream flow and the national water balance.

Overall then it may be concluded that properly managed, abstractions of groundwater of the order listed, generally would be feasible should the need ever arise. In practice groundwater is likely to be of most value in Ireland in schemes seeking not more than 5 million gallons per day.

Publications consulted during preparation of this paper.

Daly, E.P., 1982. The Groundwater resources of the southeast industrial development region. GSI report, Dublin.

United Nations Department of Technical Cooperation for Development (UNDTCD), 1991. Groundwater in Western and Central Europe. UN, New York.

Wright, G.R., C.R. Aldwell, D. Daly and E.P. Daly (EC Coord J.J. Fried), 1982. Groundwater resources of the Republic of Ireland. E.C., Th. Shafer, Hannover.

COUNTY	LIMESTONE	ORS	OTHER SANDSTONES	QUATERNARY	VOLCANICS
Carlow	X^{+}			X	
Cavan	X^{++}		X^{+}	X	
Clare	X^{++}	X		X	
Cork	X^{+}	X^{L}		X^{+}	
Donegal	X		X^{++}	X^{L}	
Dublin	X^{++}			X	X
Galway	X^{++}	X		X^{L}	
Kerry	X^{++}	X^{L}		X	
Kildare	X^{+}			X^{++}	
Kilkenny	X^{++}	X	X	X^{L}	
Laois	X^{+}	X^{L}	X	X	
Leitrim	X^{++}		X^{+}		
Limerick	X^{++}	X^{L}		X^{L}	
Longford	X^{++}	X^{+}		X	
Louth	X^{+}			X^{++}	
Mayo	X^{+}		X^{L}	X^{+}	
Meath	X^{++}		X	X	
Monaghan	X^{+}		X^{+}		
Offaly	X^{++}	X	X	X^{L}	
Roscommon	X^{++}		X		
Sligo	X^{++}		X^{L}	X	
Tipp Nth	X^{+}	X^{L}		X^{L}	
Tipp Sth	X^{++}	X		X^{L}	
Waterford	X^{+}	X^{L}		X	X^{+}
Westmeath	X^{+}	X		X	
Wexford	X^{L}			X^{+}	X^{+}
Wicklow				X^{++}	X^{L}

Table 2. Importance of major aquifers in Ireland in each county.

X = occur in county + = more than 30% of estimated GW resources in county. ++ = more than 60% of estimated GW resources in county

L = locally important

COUNTY	LIMESTONE	ORS	OTHER SANDSTONES	QUATERNARY Sd+Gv	VOLCANICS
Carlow	47			53	
Cavan	77		23		
Clare	75	24	1		
Cork	53	16		31	
Donegal	11		62	27	
Dublin	70			19	11
Galway	82	5		13	
Kerry	62	12		26	
Kildare	22			78	
Kilkenny	62	11	6	21	
Laois	55	22	3	20	
Leitrim	65		35		
Limerick	68	6		26	
Longford	67	30		3	
Louth	33			67	
Mayo	41	3	8	48	
Meath	72		1	27	
Monaghan	47		53		
Offaly	60	15		25	
Roscommon	70	7	16	7	
Sligo	69		14	17	
Tipp Nth	54	24		22	
Tipp Sth	77	3		20	
Waterford	51	16			33
Westmeath	57	28		15	
Wexford	5			48	47
Wicklow				85	15

Table 3. Percentage of each county's groundwater resources by aquifer.

COUNTY	Mm^3/yr	MGPD
Carlow	24	14
Cavan	45	27
Clare	102	61
Cork	333	201
Donegal	31	19
Dublin	8	5
(excluding Dublin city)		
Galway	356	214
Kerry	245	148
Kildare	63	38
Kilkenny	176	106
Laois	101	61
Leitrim	59	36
Limerick	289	174
Longford	29	17
Louth	29	17
Mayo	392	236
Meath	96	58
Monaghan	55	33
Offaly	64	39
Roscommon	125	75
Sligo	96	58
Tipp Nth	118	71
Tipp Sth	241	145
Waterford	114	69
Westmeath	13	8
Wexford	115	69
Wicklow	26	15

Mm^3/yr = Million cubic metres per year

Table 4. Estimated groundwater resources for each county.

(Based largely on 1982 EC groundwater resources report).

GROUNDWATER EXPLORATION AND DEVELOPMENT
THE USE OF INDIRECT METHODS OF INVESTIGATION
-REMOTE SENSING AND GEOPHYSICS-

-JEROME KEOHANE-

Note: **It is not the purpose of this paper to describe the theory and practice of indirect methods and only a very general description of the most commonly used techniques is given.**

1. INTRODUCTION

Locating suitable and productive reservoirs of groundwater is an important problem across the world. For instance three out of every five people in less developed countries have no easy access to clear water. Increasing industrialisation in developed countries is placing undue strain upon dwindling supplies of surface water so that groundwater is becoming increasingly popular. The drilling of a borehole and equipping it to produce water and so become a water well is the most general method of groundwater development. Siting exploratory, observation and production boreholes is the task on which too often a hydrogeologist is judged. Hence in siting boreholes all necessary investigations must be completed and analysed so as to obtain optimum results at minimum cost. For over 50 years geophysics and remote sensing techniques have been used successfully in groundwater exploration. Today in Africa geophysical prospecting for groundwater is as important as for mineral prospecting.

2. WHY USE INDIRECT METHODS ?

Indirect methods can be used at nearly every stage of a groundwater development scheme. Remote sensing using satellite imagery or aerial photographs can.

1. Reduce considerably the amount of field survey work.

2. Enable us to study the area of interest for important information which would otherwise be beyond our field of observation.

Remote sensing is best used when we are investigating an area measured in 10's, 100's or even 1000's of square kilometers. We hope to get information that will enable us to better focus and plan our follow on field survey. Geophysics lets us focus in on interesting areas identified from a logistical, hydrogeological or remote sensing preliminary study. The preliminary study is essentially an exercise in the horizontal dimension. With geophysics we hope to investigate in the vertical dimension as well. Geophysics is useful because,

1) We can get exploratory information at a cost considerably lower than wildcat drilling.

2 If water is related only to some special structure or feature such as karst or fractures the examinations of aerial photographs followed by geophysics has been successful.

An example (White, 1986) to show the benefits of using indirect methods is given of a project in Africa where 282 boreholes were sited using various siting techniques. If a suitable site could be located on a hydrogeological or air photo basis only, then no additional time was taken by substantiating the investigation with a geophysical survey. The analysis of all the data at the end of the project enabled each borehole to be categorised into six main classes depending upon the techniques used to site a borehole. The classes used and the percentage of boreholes falling into each class is given in Table 1.

In class 1 boreholes were sited purely on convenience grounds and ease of access. In classes 3-6 hydrogeological survey techniques were used. Similarly, aerial photographic interpretations were taken into account in classes 4-6 but remained the main technique used in class 3. In classes 4-6 boreholes were sited mainly on the results of the geophysical investigations conducted. In class 6 this reliance was split between both geophysical techniques. The success of each siting method was determined in terms of the probability of achieving a given specific capacity (yield per unit drawdown) for each borehole. The results are summarised in table 2 where the success rate of each technique is given. A similar study on the success of siting boreholes in Ireland might yield interesting results.

TABLE 1
BOREHOLE SITING TECHNIQUES

		%
1	LOGISTICAL	0.9 %
2	HYDROGEOLOGY	18.3 %
3	AIR PHOTO	7.5 %
4	EM	21.8 %
5	RESISTIVITY	34.7 %
5	EM/RESISTIVITY	16.8 %

TABLE 2 SUCCESS RATE FOR SITING TECHNIQUES		
1	EM/RESISTIVITY	90 %
2	RESISTIVITY	85 %
3	EM	82 %
4	HYDROGEOLOGY	66 %
5	AIR PHOTO	61 %
6	LOGISTICAL	50 %

(Success measured in the probability of achieving a given specific capacity (yield per unit drawdown).

cc: White - Hydrotechnica from 'Third World Development' June 1986

3. PLANNING A SURVEY

Efficient planning and survey design are important in obtaining realistic results from a remote sensing exercise or a geophysical survey. We must however account for the following constraints.

- Has the borehole(s) to be sited within a restricted area, a field, a farm, or part of a county.

- Cost/benefit ratio: indirect methods are not always the most effective method of obtaining the information needed eventhough they may be cheaper .

- Consultation of reliable, available geological, hydrogeological and borehole information for an area saves a great deal of time and money as it enables a more specific survey design.

- Indirect methods are not a stand alone technique. They require verification by drilling and other field surveys.

4. FINDING WATER

Groundwater in Ireland is mainly abstracted from two types of aquifer.

1) The unconsolidated sediments

2) Bedded fissured, and fractured rocks

Indirect methods can be employed in the development of water from these sources.

4.1 Remote Sensing

As groundwater occurrence cannot be observed directly on the surface of the earth, remote sensing interpretation makes use of information obtained from the controlled study of elements of the geology morphology and vegetation expressed on the records. Aerial photographs are an instantaneous impression of dynamic processes whereas satellite recording may allow you to observe seasonal variations. So the requirements of the study should be established first. Remote sensing interpretation may be summarised in the following sequence.

1. Observation

2. Identification of elements, such as fractures, lineaments, catchment boundaries, lithological boundaries, morphological features.

3. Analysis of the elements in relation to their environment and the making of conclusions based on knowledge and experience

4.2 Geophysics

The application of the various geophysical methods to finding water is well documented elsewhere in text books. Regardless of the method used the efficacy of each relies on the contrasting physical and physical-chemical properties of the water and the various layers of the earth materials.

4.2.1 Unconsolidated Sediments

These sediments are collectively known as quaternary deposits. Where they are mainly of fluvioglacial origin and granular they are usually permeable and outcrop with thin soil cover. As they occur just below the ground surface they are readily explored by a variety of geophysical techniques. The information that we require from a geophysical survey is,

1) Depth to bedrock
2) Variation in bedrock topography
3) Depth of water table
4 The lateral extent of these aquifers under superficial cover (e.g. bog or topsoil)

In Ireland electrical resistivity has been most widely used either in the sounding mode (vertical electrical sections) or in the profiling mode. Seismic has been used where the speed of sound in bedrock is greater than that in the overlying sediments and has successfully been used to profile bedrock. Electromagnetic profiling has been used to map variations in thickness of the sediments. More specialised usage involves the use of gravity equipment whereby variations in the thickness of deposits can be related to variations in density measured by gravity meters. other techniques such as induced polarisation have been used in limited situations.

4.2.2 Fractured and Fissured Rocks

We are looking for fractures and fissures, crushed zones and joints. The object of geophysical exploration is to locate such features. Generally the overburden which may consist of transported material or the produce of the in-situ weathering of the underlying bedrock is of small thickness so that the water bearing systems commonly lie at shallow depth. If overburden is unusually thick geophysical methods may be needed for finding its thickness apart from locating fracture joints.

Generally in Ireland resistivity profiling is the most widely used technique. The main choice to be made in this survey is the spacing between the electrodes. We would hope to find a decrease in resistivity over the water bearing structures or the areas considered best for further investigation by drilling.

The Electromagnetic Method (EM) is less widely used but relies on a similar measurement to resistivity. The object of EM surveying is to locate subsurface conductors. In hydrological exploration these conductors may represent local groundwater occurrences in fractured zones. Examination of aerial photographs may indicate certain linears which may be fracture zones in hard rock. EM profiles allow the presence of these fractures to be readily verified and the exact location of boreholes in the field established. The problem with using this equipment in Ireland is one of conductive overburden with inhomogeneous electrical properties in the form of varying thicknesses rather than varying conductivities. In certain cases the overburden conductivity may be so high that any variations in thickness may seriously distort the resulting EM field anomalies from a fissure zone.

Other techniques used at one time or another in Ireland are the VLF which is a variation on the EM technique and ground penetrating radar.

Other geophysical techniques worth considering in both aquifer types are well logging techniques. This area includes all techniques of lowering sensing devices into a borehole and recording physical parameters that may be interpretable in terms of the borehole rock characteristics and the fluids in the hole. The spectrum of information obtainable from the interpretation of geophysical well logs includes the exact position of formation boundaries and thickness, identification of thin individual beds, bulk density of the rock, approximate total porosity ands approximate conductivity of the fluids filling the hole.

5. CONCLUSIONS

It can be shown that the use of indirect methods can give useful information on the development of groundwater. However we can also see the limitations of such methods. The main point that I would like to emphasise in this paper is that indirect methods on their own are not the answer to all problems. Proper input of other relevant information ensures accurate interpretation and the use of more than one technique enhances results. The cost of surveys need to be considered in the context of overall project development costs and only then can the cost to benefit ratio be significant. I would like to see better statistics on the past use of indirect methods in Irish groundwater investigations so that we can better direct the future use of these useful methods in Irish groundwater investigations.

International Association of Hydrogeologists
(Irish Group).

12th Annual Seminar .

Pumping Tests.

Speaker: Kieran O'Dwyer

(Kevin. T. Cullen and Company Ltd,)

PUMPING TESTS.

Groundwater resource evaluation involves of a series of steps. Desk study, geophysical surveys, trial well drilling, pumping tests, aquifer modelling, hydrochemical studies and production well drilling. This paper will deal with pumping tests and will concentrate on the practical approach rather than the theoretical mathematical methods of data interpretation. The complexity of any pumping test is governed by the end use of the well and the information required. I have attempted to classify pumping tests on the basis of these requirements.

The paper will also comment on the practicalities of conducting a pumping test and hopefully will provide some insight into problems that can occur accumulating field data.

Pumping Test Apparatus.

Pump.

The selection of a pump for the pumping test is dependent on several factors. A crude estimate of the potential yield of the well can be made during the drilling operation. A pump should always be selected that can deliver at a greater rate than this estimate. Most trial wells drilled in this country have an internal diameter of 150mm. The maximum output from a submersible pump that can be accommodated within this diameter is ≈ 3,700/hour (400m3/day). In many cases larger pumping rates are required. These can be achieved by using a positive displacement "Mono" pump. Yields of up to 2,500m3/day (23,000g/n) can be abstracted with this pump. In most cases there is no three phase power available and consequently a generator is required. In the case of the "Mono" pump the power can be supplied by the P.T.O. of a tractor.

Gate Valve.

An ability to vary the output of the pump is required. This is usually achieved by a gate valve on the discharge line. In the case of the "mono" pump, the pumping rate can be varied by adjusting the revs of the tractor engine.

Flow Measurement.

Throughout the pumping test it will be necessary to measure the output. An integrating flow meter should be used with an alternative method as a back-up. The discharge from a trial well can be quite gritty initially which can sometimes cause the flow meter to stop. When using flowmeters ensure that the clock is dedicated to the impellers within the meter or considerable measurement errors will result. The flow meter must always be at least 15 pipe diameters from any bend or valve. The most convenient back-up is a tank of known volume. If the time to fill this tank is recorded the output can be calculated. In cases where large volumes are pumped a "V" notch weir tank can be used.

Discharge Pipe.

Flexible discharge pipe is recommended as the discharge may often have to be conveyed considerable distances over uneven ground.

Water Level Meter.

The water level in the pumping well and observation wells must be measured regularly throughout the test. The best method is an electrical contact dipper (always have a spare on site). An on air line pressure gauge may be used but is not as accurate. When using electrical contact dipper in the pumping well, a narrow 15 mm I.D. pipe should be installed in the well along with the pump. This eliminates erroneous readings due to cascading and prevents the tape becoming entangled in the pump and cable. In the case of tests involving a lot of observation wells the use of data loggers should be considered. These can provide detailed data and result in big reductions in manpower requirements.

Sampling Tap.

A sampling tap should be inserted at the well head on the discharge line to facilitate the collection of water samples.

Objectives of a Pumping Test.

The primary objective of a pumping test is to establish the quantity of water that may be safely abstracted from the well under test and the drawdown that will be associated with this abstraction rate. A pumping test is also designed to determine the hydrogeological characteristics of the aquifer. (In order to determine these, observation well data must be collected, however in the case of simple single well water supply the cost of construction of observation wells is not justified or absolutely necessary). Using these characteristics (namely Transmissivity and Storage coefficients), predictions can be made on how the aquifer will respond to, long term pumping, the development of well fields and the mutual interference between individual wells. These predictive and impact studies are conducted using mathematical models. The aquifer characteristics used in the models must be established by conducting pumping tests. When the pumping test data has been analysed a suitable pump and the level at which it should be placed can be selected. The discharge at the end of a pumping test is usually representative of the groundwater and therefore samples should be taken at this stage and sent for chemical and bacteriological analyses.

Information Required to Assist Data Interpretation.

Apart from the data generated by the pumping test, there are other elements which assist in its interpretation.

(a) Inflow Levels:

During the drilling operation an accurate record should be kept of the levels and estimated quantity of the inflows to the well. This is of particular importance in fissured rock aquifers. The effective depth of a well is equivalent to the depth to the lowest inflow entry. The remainder of the well beyond this acts as a sump. Similarly once the water level is drawn below any water bearing fissure (inducing cascading), the contribution to flow from that point cannot increase.

TRANSMISSIVITY (T)

"The coefficient of transmissivity T of an aquifer is the rate of flow of groundwater through a vertical strip of unit width, which extends the entire saturated thickness of the aquifer, under unit hydraulic gradient and at the prevailing groundwater temperature."

Units = m^3/day

STORAGE COEFFICIENT (S)

"The coefficient of storage S of an aquifer is the volume of water it releases from, or takes into , storage per unit surface area of the aquifer per unit change in the componant of the head normal to the surface"

Units = Dimensionless

S = 0.05 - 0.3 for Unconfined Aquifers

S = 0.00001 - 0.001 for Confined Aquifers

(b) Potential Boundary Conditions.

The location of all nearby streams should be noted as they may constitute recharge boundaries. Any changes in geology or faulting that may act as impermeable boundaries should also be noted.

(c) An inspection of the drilling log should establish if the aquifer is confined, unconfined, or leaky.

Step Tests.

This test is designed to measure the performance and efficiency of the pumping well. It is a well test rather than an aquifer test. The test consists of a series of steps (usually 4) during which the well is pumped at increasing pumping rates for a specific period of time (100 minutes). Analysis of step test data will provide the following;

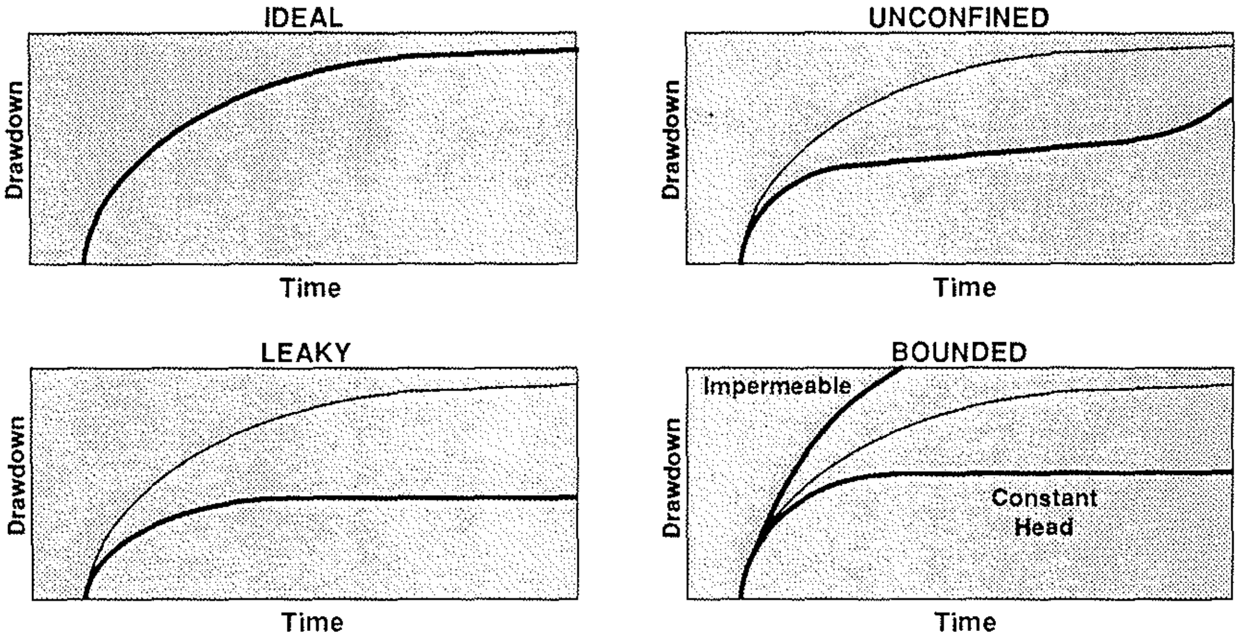
i) The variation of drawdown with discharge, enabling a pump to be selected for the aquifer test.

ii) The efficiency of the well can be determined and the well loss estimated.

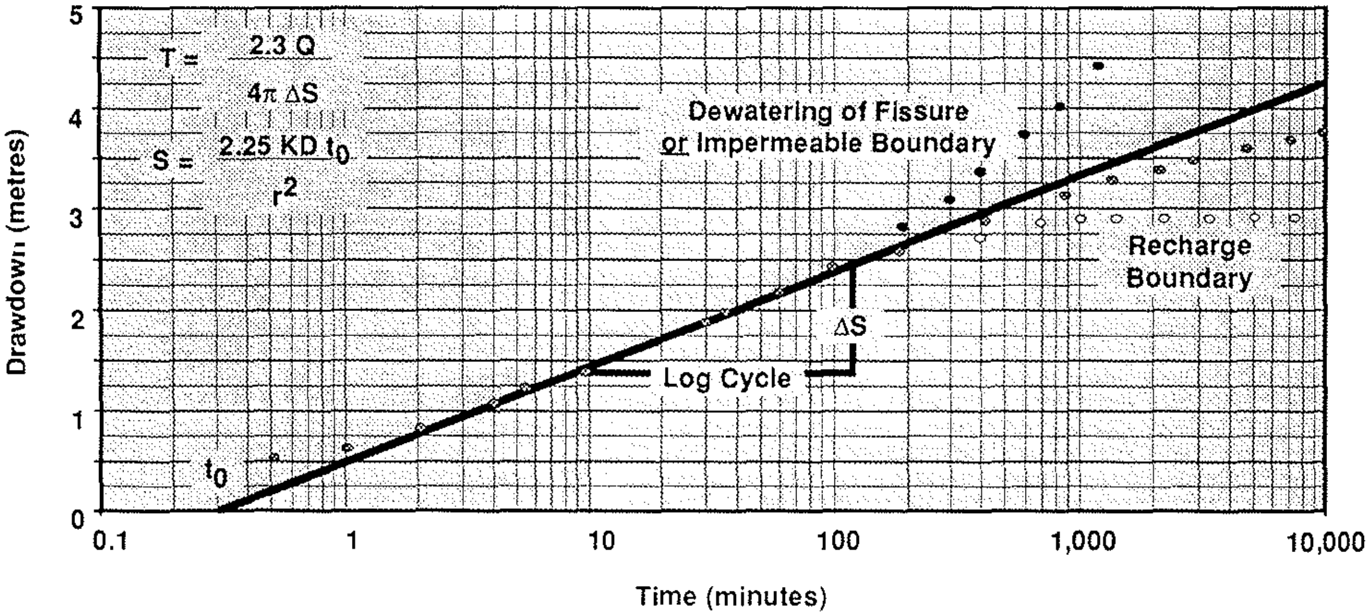
iii) The step - drawdown test can be used to evaluate if there is any deterioration in the well performance at a later date by simply rerunning the test and comparing the results.

Constant Yield Tests.

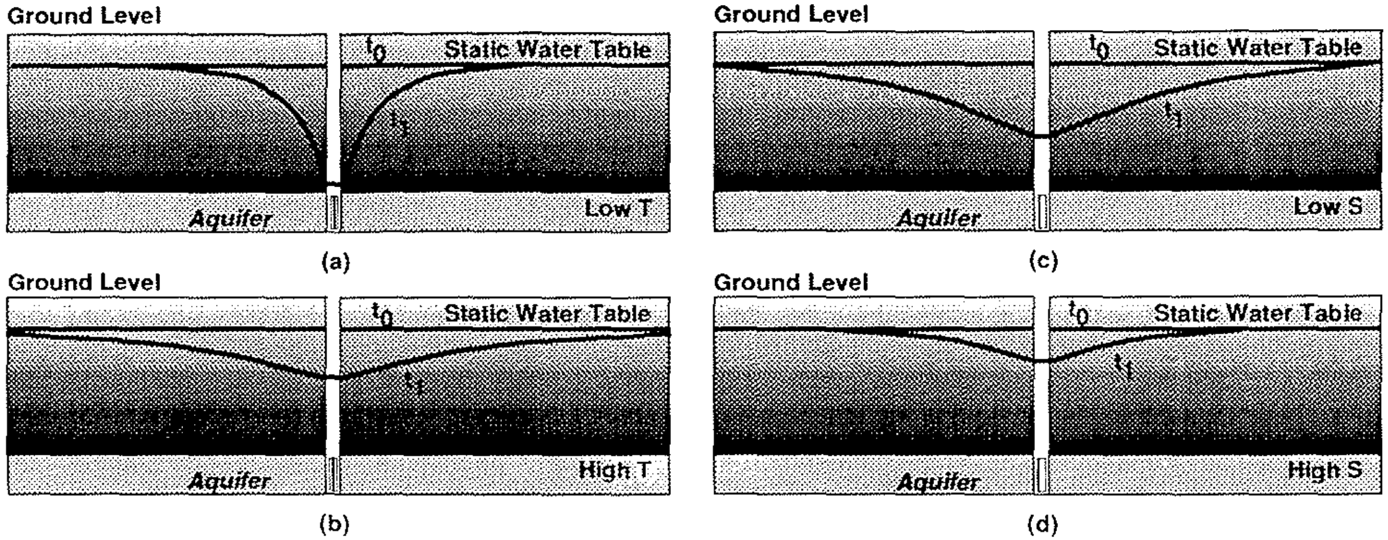
This test consists of pumping the well continuously for a given period (usually 3 days) at a constant pumping rate. The amount of data required for a particular test is dependent on, the ultimate end use of the well, its yield and its interaction with other elements of the hydrogeological cycle. In order to be able to make predictions on the response of the aquifer



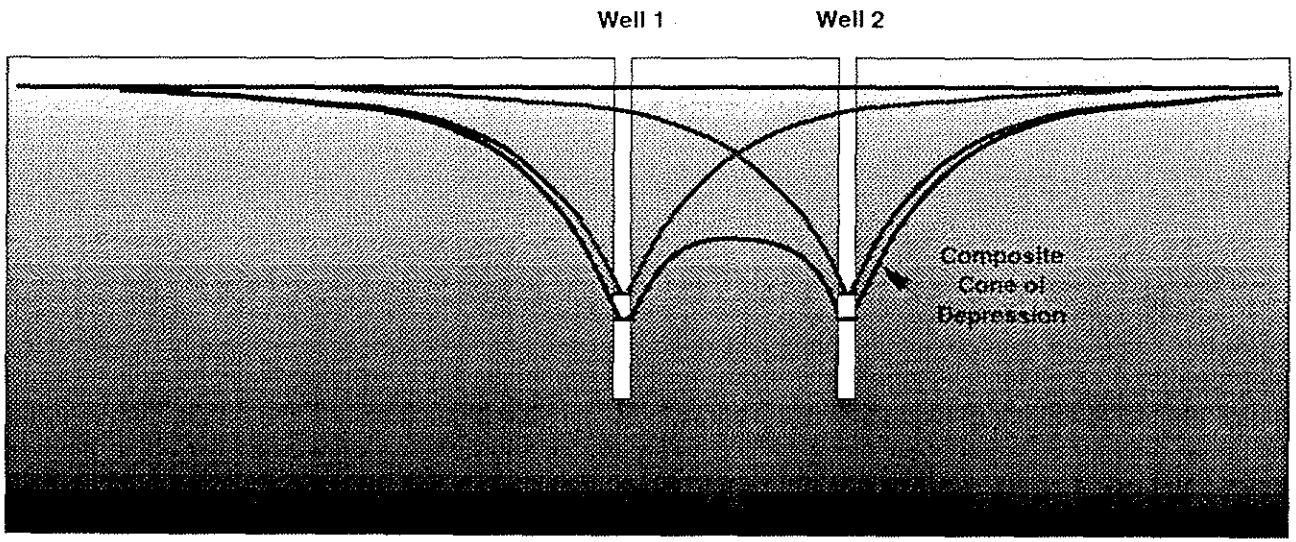
LOG - LOG TIME DRAWDOWN PLOTS FOR DIFFERENT AQUIFER TYPES



SEMI-LOG PLOT OF OBSERVATION WELL DATA (JACOB)



CONES OF DEPRESSION ASSOCIATED WITH DIFFERENT AQUIFER CHARACTERISTICS



Interference between two pumping wells

(rather than the well itself) to abstraction it is necessary to determine the aquifer characteristics (coefficients of storage and transmissivity). Good quality observation well data is required to calculate these coefficients. If this level of analysis is required (and there are no suitable observation wells in situ) it will be necessary to construct observation wells with piezometers installed.

Pumping Test Catagories.

In order to give an indication of the degree of input required for different pumping tests, I have outlined four categories below.

<u>Class I</u> (Domestic wells, Farm supplies, 20-50 m3/d).

Information required.
- Safe yield of well. (intermittent use)
- Pump selection.
- Water Quality

Duration - 24 hours.

<u>Class II</u> (Supplies to industry, Group schemes, and supplies of 50-200 m3/d)

Information Required.
- Safe yield of well (may pump continuously)
- Pump selection
- Water Quality
- Effect on nearby wells (within 200 metres)
- Time-drawdown plot to assess fissure dewatering.

Duration - 72 hours and recovery test (2 hours)

Class III (High yielding supplies to industry, Single well public water supply, Exploration wells which form part of regional groundwater development study, yields of 200-600 m3/d)

Information Required.

- Safe yield of well
- Pump selection
- Water Quality
- Impact on all local wells within 1 kilometre.
- Zone of influence
- Aquifer characteristics (where useful observation well data is available)
- Meteorological data
- Design of production well

Duration - 3 - 5 days and 24 hour recovery test

Class IV (Phase II of regional water supply schemes, Large scale dewatering projects, Environmental impact studies and single well yields greater than 700 m3/day)

Information Required.

- Safe Yield of Well (taking into account interference from other pumping wells)
- Pump selection
- Water quality
- Aquifer characteristics (T,S)
  This requires observation drawdown data at various distances from the well and at boundaries (Rivers, Lakes, Faults Etc.)
- Impact on groundwater table.
  Water level must be recorded in remote wells to establish natural fluctuation.
- Impact on streamflow.("V" notch weirs)
- Impact on environmentally sensitive features (Bogs, Fens, Turloughs Etc.)
  Multi-level piezometer nests need to be constructed.
- Aquifer Recharge (determined with aid of meteorological data)

All the above information can then be used to create and calibrate a mathematical regional groundwater model. Data loggers which automatically record water levels are a a great labour saving device when tests of this scale are carried out.

Summary

The quality and diversity of data that must be collected from pumping tests varies enormously and is dependant on the impact that the use of the well will cause. The cost of a pumping test programme can run from a few hundred pounds to tens of thousands of pounds. With the advent of greater environmental awareness and legislation and the need to conduct environmental impact studies. The role of the pumping test has become much more than establishing if the water demands of the owner can be met by a well. It has now become necessary (in case of larger groundwater abstractions) to determine the impact on a wide variety of environmental features. As the optimum surface water abstraction sites become developed and potable water becomes scarcer, the development of groundwater as regional water supplies will become increasingly more attractive. In these cases it will be necessary to quantify the available resource in order to avoid overpumping the aquifer. To this end the water balance and recharge to the aquifer will have to be estimated in order to quantify the safe yield of the aquifer. Hitherto pumping tests have been concerned with the safe yield of individual wells. When large scale abstractions are developed in coastal regions the risk of saline intrusion will have to be quantified.

No matter what class of test is being conducted the every effort should be made to ensure that the data is of such a quality that the best use can be made of it. Tests should be carefully planned and the maximum amount of data possible collected. Irrelevant data can always be discarded at a later date.

Groundwater Computer Models.

by Kevin T. Cullen.

The past fifteen years has seen groundwater models increase in importance from mathematical curiosities to an every day tool of the trade for the practising hydrogeologist. Models have their diehard supporters which tend to be drawn from the more academic side of the science. Critics of modelling abound in the ranks of field orientated hydrogeologists who find the many assumptions made by the modellers to be far removed from field reality. No matter what view one takes of hydrogeological models, one thing is certain, they will play an ever increasing role in our understanding of groundwater systems on both local and regional scales.

The value of groundwater computer models depend on the accuracy of the input data. While many of the the parameters in aquifer studies can be quantified in some detail such as rainfall, evapotranspiration, stream flow and water table fluctuations, other items such as transmissivity (T) and storage (S) are generally less predictable. In addition, even where individual values of T and S are available, the regional variation of these parameters limit the overall accuracy of the model. Despite these reservations and the difficulty of defining boundary conditions, aquifer models are useful in providing regional water balances and predicting the likely impact of major groundwater withdrawals.

On a more local scale groundwater models are of value in determining the impact of quarry dewatering, effluent discharges to ground and the extent of well capture zones. In the absence of historical data developers are now being asked by planning authorities to indicate the impact of dewatering on the water table, nearby wells and wetland features such as bogs. Where effluent is being discharged to the groundwater system the licensing authorities have asked for model prediction as to the impact of the discharge on groundwater quality and ultimately on local surface water quality.

The use of models to define the impact of developments on groundwater will increase as the regulatory authorities require a higher level of information regarding various aspects of the hydrological cycle. It is therefore important that those using and adjudicating on the results of modelling exercises are fully aware of the many and varied assumptions used in the modelling exercise.

INTERACTIONS OF GROUND AND SURFACE WATER SOURCES, IN THE THAMES WATER UTILITIES AREA

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740mm R.
490. Ev.
55% of Residue used for water supply.

INTRODUCTION

This paper is set against the background of the water industry in the United Kingdom. Legislation covering water has been devolved with Scotland and Northern Ireland having different and independent legislation from that covering England and Wales. All the the discussion will be concerned with the situation in England and Wales.

All abstractions, with the exception of some made by the Crown, must be licenced. This has been the case since the passing of the Water Resources Act in 1963 and has been incorporated in all subsequent legislation. Licences are now issued by the National Rivers Authority (NRA) unless an application is so contentious that it is "called in" for determination by the Secretary of State for the Environment. The information required on application and the conditions imposed upon the licence holder are becoming increasingly onerous.

It is against this background of a heavily regulated water industry that groundwater development by Thames Water Utilities (TWUL) will be discussed. The importance of groundwater both now and in the future will be reviewed.

BACKGROUND

Table 1 shows total licenced abstractions for all purposes (except power generation) for England and Wales and the Thames basin.

Table 1

	Proportion abstracted(%) 1990	
	Surface	Ground
England and Wales	67	33
Thames Basin	46	54
Thames Basin-public water supply	42	58
Thames Water Utilities	74	26

There are significant abstractions from groundwater in all parts of England and Wales, although in Wales and the south west and west of England it represents only around 15% of the total. The Thames basin is typical of the chalk and limestone areas of the south and east.

Table 2 shows the quantity of water put into public supply in 1990/91 both in England and Wales, by TWUL and by the other water companies operating in the Thames basin.

Table 2

	Public water supply(Ml/d) 1990/91
England and Wales	17381
Scotland	2300
Northern Ireland	680
Thames Water Utilities	2795
Thames basin water companies	1225

In the Thames basin many agricultural and industrial concerns, particularly breweries and food processors, have their own licenced sources so that when their needs are added to the public supply, abstraction in the Thames basin exceeds 4500 Ml/d.

It must be noted that rainfall in the basin is, on average, 704mm compared with an England and Wales average of 912mm. When evaporation is taken into account, on average 510mm, the balance between supply and demand is a delicate one as the last four years of drought in the south east of England have shown. It has been calculated that in an average year 55% of the effective rainfall on the basin is used. This makes the Thames basin one of the most intensively used water resources systems in the world.

THAMES WATER - WATER RESOURCES STRATEGY

The Director General of Water Services (OFWAT) issues operators' licences to the water undertakers in England and Wales. Under the terms of that licence the undertaker must make resources available to meet the level of service shown in Table 3.

Table 3

Level of Service for Water Resources

Measure	Average Frequency (years)
1) Hosepipe bans	Not more than 1 in 10
2) Intensive publicity campaigns, leakage control etc	Not more than 1 in 20
3) Bans on inessential by Drought Order	Not more than 1 in 50
4) Use of standpipes and/or rota cuts by Drought Order	Not more than 1 in 100

Performance against this target is monitored and reported annually to the Director General. He also carries out technical audits both of the current situation and company plans to meet this target over a 25 year planning horizon, currently to 2016. Although broadly in balance for the company area as a whole, TWUL does not meet this standard in some areas and has plans for major resource developments. Groundwater is an important part of these plans and in addition to conventional new sources, artificial recharge is also being developed. TWUL is also progressing major initiatives in surface water resources and is in the site investigation stage for a major new reservoir near Abingdon in Oxfordshire.

For London the major source of supply is surface water from the rivers Thames and Lee stored in pumped storage reservoirs with a total capacity of 207 million cubic metres. Groundwater is also used in two area, in part conjunctively with surface derived water. An artificial groundwater recharge scheme is currently under construction to help meet the level of service deficit. The first stage is expected to produce 90 Ml/d. A second stage is being investigated and it is hoped that a further 90 Ml/d will be possible. Exploiting the rising groundwater under central London is also being investigated and this could yield a further 30 Ml/d.

Outside London the emphasis is much more on groundwater, although there is another major pumped storage reservoir complex of 13 million cubic metres capacity near Oxford. Groundwater sources vary in size from individual wells and boreholes serving small local areas, with yields as low as 0.01 Ml/d, to major strategic developments of up to 70 Ml/d. The typical size is in the range 5-15 Ml/d.

Prior to the reorganisation of the water industry in 1974, water service suppliers were generally quite small and served only a local area. Since the creation of larger units the move has been much more towards the concept of integrated river basin management. This has meant that the main thrust of resource planning has been towards the development of strategic resources to suport local developments, increased recirculation and the conjunctive use of surface and groundwater resources. This does not mean that local development does not take place where it is environmentally acceptable but the emphasis has tended to shift.

PROCESS OF GROUNDWATER DEVELOPMENT

Under the Water Resources Act 1991 it is the duty of the NRA to conserve, redistribute or otherwise augment water resources and further to secure the proper use of water resources. It is however, the duty of the water undertaker, under the Water Industry Act 1991, to provide water supplies to those who demand them and for ensuring that there are adequate supplies to meet those demands. It may be seen that there is the potential for conflict in the satisfaction of these two distinct duties. There are detailed procedures for obtaining a licence to abstract water. The public has the right to participate in the decision making process along with the right to object. Licencing can therefore be both an expensive and time consuming business.

It is an offence for any person either to construct a borehole and/or to abstract from underground strata without a licence from the NRA. In order to abstract a person must be the occupier of the land or satisfy the NRA that he has entered into negotiations to aquire an interest in the land. If such an interest is obtained they must further be satisfied that rights exist to ensure that the applicant will be entitled to occupy the land.

Once an area has been identified as likely to be suitable for groundwater development, the first stage is therefore to enter into negotiations with the landowner. The end point of this negotiation usually takes the form of an option to purchase sufficient land for the borehole(s), headworks and any treatment plant together with access should the resource be proved. This can be a very long process. TWUL, as a statutory water undertaking, does ultimately have the right of compulsory purchase, unusual for a private company, but it is a power that would be used very reluctantly.

When the negotiations have been concluded and permission to sink exploratory boreholes has been granted, work can commence. The next stage is to test the yield. As it is illegal to abstract without a licence, there is a provision in the Water Resources Act 1991, for test pumping to be carried out with the permission of the NRA. Clearly it is not feasible to go through the full licencing procedure unless an acceptable yield has been proven. At the same time as test pumping to establish yield is carried out, monitoring will be required by the NRA to ascertain the effect of abstraction on any other well or borehole and on streams, lakes, ponds etc. in the locality. This information will be used in determining any licence application.

The final stage in bringing the source into production is to obtain the licence. The NRA has recently issued new guidelines on the information required in support of a licence to abstract. This information requirement is comprehensive and includes the demand forecasts (component based) used to justify the scheme, historic information on water consumption and full details on targets, performance and policies on leakage control. They also require information on the yields and use of existing sources and, for groundwater, the extent to which conjunctive use with surface water schemes is carried out. A full consideration of options, including major schemes such as inter-basin transfers, is also needed. This is to include costs and an assessment of the impact of metering and other demand management measures on the area. Finally information must be provided on the environmental impact, not only of the proposed scheme but of all the options considered.

The above information must be fowarded to the NRA with the application for a licence. At the same time the application must be formally advertised in local newspapers and in the London Gazette, which is the forum for official announcements. There is then a period of twenty eight days during which any person can make representations about the proposed licence. The public is becoming increasingly aware of environmental issues and applications are now much more likey to attract interest. Often these potential objectors can be satisfied by discussion but some objections are sustained. Unless the representations are seen by the NRA as being serious, or the proposal is particularly contentious the NRA is empowered to determine the licence themselves. It may however, be referred to the Secretary of State who may decided to "call in" the application and determine it himself, often following a public inquiry.

In addition to the water resources licence the new source may also require a consent under town and country planning legislation for the headworks and buildings. The rights of public representation and objection also exist under this legislation. Under normal circumstances the planning application is made after at least outline approval has been obtained on the abstraction licence. If however, the application is called in, it is usual for any public examination of a proposal to cover all relevant legislation. Typically there is a period of several months between making an application and a licence being granted. A public inquiry , inspector's report and decision by the Secretary of State will add considerably to this time scale. Periods of a year or more are not uncommon.

INTERACTION OF GROUND AND SURFACE SOURCES

The basic concept in resource development is to provide local sources wherever they are environmentally sustainable, supported by major strategic resources. This concept is well demonstrated in the upper Thames area shown in Figure 1. Here the local groundwater sources in the Swindon area have been interlinked by a trunk main network augmented by a link to the Farmoor storage reservoirs and treatment works near Oxford. This has in turn lead to a need for new resources in the Oxford area. This has been satisfied by the development of a major new groundwater source at Gatehampton. This has in fact set up a recirculation system with water abstracted at Oxford being returned as treated effluent from Swindon and therefore being available for reabstraction.

The development at Gatehampton is typical of groundwater sources whatever their size. This source was developed in two stages and is now fully licenced to provide an average yield of 70 Ml/d and 105 Ml/d peak. It is now based on a well field of seven boreholes. The original source on the site was licenced for 15 Ml/d in the 1970s. Further investigations indicated that a much larger yield was possible. Detailed planning began in 1982 with borehole drilling and test pumping carried out in the mid 1980s. The licence application for the full development was made in 1989 but not granted until 1991. The licence has a number of restrictive clauses which illustrate the current position of the NRA and its perception of the protection of the aquatic environment.

The licencing of the Gatehampton source was very protracted. There was an objection from British Rail, which operates a main railway line adjacent to the site. This runs along an embankment and there was natural concern about the stability of this structure. Although this objection was outside water resources and planning law the NRA delayed a decision on the application. Following a long period of negotiation and an independent report by a consultant, TWUL have agreed to indemnify British Rail in the event that its abstraction works have an impact on a defined area of British Rail land.

Under the terms of the licence the NRA has imposed two important conditions on the use of water from the source. First, no more than 5Ml/d of water may be used outside a defined area upstream of the source. Second, although a groundwater source, peak abstraction has been limited by means of a flow constraint on the river Thames. In addition there is a requirement for 12 observation boreholes at locations to be agreed with the NRA.

The two conditions impose constraints on the operational flexibility of this key resource. In particular the restriction on the peak could bring foward the need for addditional resources. In other resource developments it is becoming clear that the environmental regulator expects to have an influence on the operations of the water undertaker. This will be either through the licencing process or through the formal operating agreements which are encouraged by the Water Resources Act. This influence is however, without financial responsibility.

COST OF RESOURCE DEVELOPMENT

Groundwater developments are still economically attractive. Table 4 shows a comparison between resource costs as published in the recent NRA discussion document on water resources strategy.

These indicative costs for groundwater are broadly correct in the Thames context. As the need for more expensive treatment of groundwater becomes more significant, to deal with nitrates or pesticides for example, costs will move towards the upper end of the band. Groundwater is economically attractive when it is environmentally acceptable.

Table 4

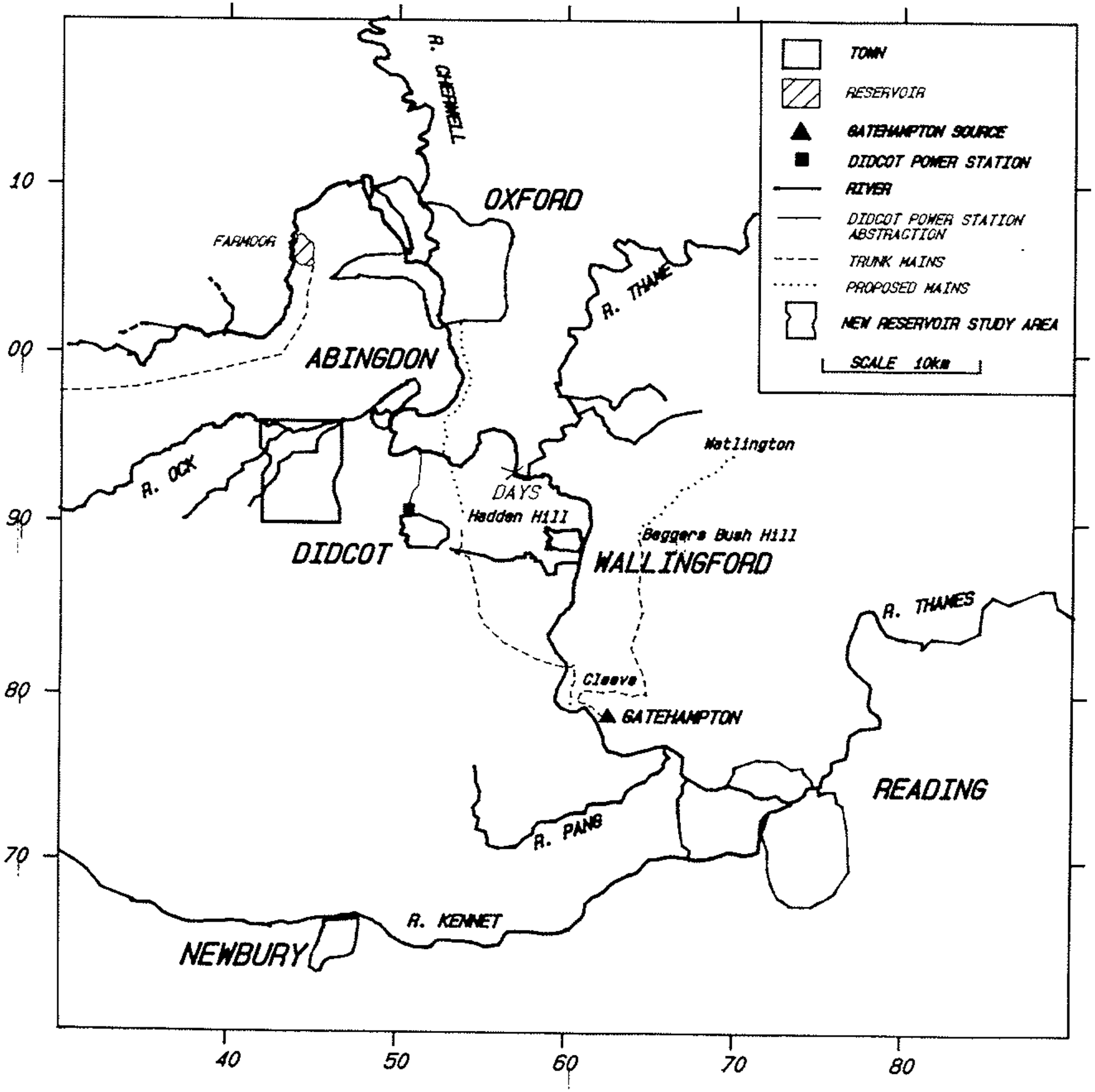
Resource Option Indicative Cost

	£million per Ml/d
Groundwater	0.1 - 0.5
Direct river abstraction	
Demand management	
Reservoirs	0.5 - 2.5
Inter-basin transfers	
Effluent re-use	
Inter-regional transfers	2.0 - 5.0
Transfers from Europe	
National water grid	4.0 - 6.0
Desalination	

It is recognised by all sides of the industry that cost will be an important factor in the selection of developments. The need will be to create the suitable mix of environmentally sensitive resources that meet the needs of the customer, that has been the theme of this paper.

FIGURE 1

MID-THAMES WATER RESOURCE SYSTEM



CATCHMENT WATER BALANCE

SOME CASE STUDIES IN IRELAND

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CATCHMENT WATER BALANCE

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1. INTRODUCTION AND SUMMARY

Small scale development and protection of water resources for domestic, agricultural and industrial needs may be successful with little or no recourse to hydrological techniques. However, without the aid of hydrological methods such as water balance, large scale development and efficient management of water resources is impossible.

This review examines three water balance studies, on the River Moy, on Lough Scur and on the River Liffey. The Liffey Study is presented in some detail.

The results highlight the importance of letting recorded data "speak for itself" before attempting more extensive detailed fieldwork and analysis. The small number of studies carried out exhibit consistent results in areas such as actual evapotranspiration derived from the water balance, when compared with the measurement of potential evapotranspiration. Total groundwater and soil moisture storage varies from its lowest level at the end of August to a high which extends throughout the months of January and February.

Applications in Ireland include verification of records of rainfall and runoff, conceptual modelling of surface water flows and assessment of water resources for multi-purpose reservoir operation.

2. RIVER MOY

The study of the River Moy in Co. Mayo highlighted the benefits of the water balance technique in data verification. Preliminary analysis indicated a serious imbalance from a particular date onward; a check on the records revealed a change in the method of runoff measurement which required an adjustment. This adjustment brought the figures back into balance.

A water balance study should be a prerequisite to any analysis of rainfall or runoff so that records are consistent.

Actual evapotranspiration (AE) was derived from the water balance equation on the River Moy. Comparison with measurements of potential evapotranspiration (PE) yielded the result:

$$AE = 95\% \ PE$$

This is considered to be typical for most catchments in Ireland.

Annual AE varies from 400mm to 450mm in most areas. Figures up to 512mm were observed in the dry year of 1975.

3. LOUGH SCUR

An analysis of water resources at Lough Scur was undertaken for the purpose of water supply to the Ballinamore and Ballyconnell Canal. This canal links the Shannon and the Erne Navigation Systems, through Counties Leitrim, Cavan and Fermanagh. "Losses" in the catchment area at the summit level, including the reservoir at Lough Scur, were calculated on the basis of rainfall input less outflow, over a ten year period. These "losses" were compared with the measured PE and they were considered to be high. The lowest flow on record is a mere 7 litres/sec.

Soil moisture storage is virtually negligible on this upland catchment; it consists of heavy clay soil on limestone. The limestone outcrops over a significant section of the canal at the summit and some fissures are evident.

The analysis was extended to a larger catchment area downstream of Lough Scur, to St. John's Loughs. Here the "losses" were considered to be in the normal range for evapotranspiration and they compared well with the measured PE. Hence the losses to the underlying limestone at the summit are recovered in a short distance downstream.

The results were used in the planning of the pumped water supply system to the summit and in the identification of areas of canal which will be lined to prevent seepage loss.

4. RIVER LIFFEY

The River Liffey rises at about 760 mOD in the peat covered slopes of the Kippure and Tonduff mountains, which are only 20km from the sea at Dublin Bay, yet from the source the river takes a circuitous route some 120km long to outfall to the sea in Dublin City. A catchment plan is shown in Figure 1.

At Pollaphuca the River enters a rock gorge and swings round to a westerly direction. Downstream, the river forms a deep wide valley in glacial drifts.

A longitudinal section of the river is presented in Figure 2.

4.1 Geology - Glacial Effects

In pre-glacial times, the topography of the Liffey basin differed little from the general form which it now presents. The filling of the valleys with glacial drift and the heaping up of moraines have made local modifications, but the main topographic features are the same. The drainage system was, however, very different.

The present area of the Liffey basin was divided between the catchments of two quite separate streams. One of these catchments included the hill-encircled basin of the upper Liffey. The outflow from this area can be traced as far as the Curragh, around Kilcullen, where it passes in a westerly direction, out of the present catchment area. The other catchment was that of the Rye Water which appears to have been, in pre-glacial times, about the same area as at present. The connection between these two basins is post-glacial in date.

In the Curragh bedrock was measured by the Geological Survey Office (GSO) to be 75m below the surface, in spots, with the average between 30-45m. The GSO has also identified the presence of an aquifer on the boundary between the River Liffey and River Barrow.

The "Curragh Aquifer" has an estimated area of approximately 200km^2 , and contains available water resources of 54 x 10^6 m^3 per annum.

It is estimated that about 80km^2 of this 200km^2 is in the River Liffey Catchment. Since 1974 the GSO have been measuring the water level in a well at Eyrefield as shown in Figure 1.

A number of interesting points can be established from the Eyrefield levels.

1. Very little variation has taken place in the water level since measurements began.

   The lowest level occurred on 22nd October 1976 and the highest on 2nd April 1980. The difference between these two levels is 1.25m.

2. The depth from the surface of the well to the water is approximately 20 to 25m. The gravels of the aquifer have a high permeability of approximately 200 m/d.

3. Following a heavy rainstorm no variation in the water level takes place.

The conclusions drawn from other borehole records throughout the catchment are that the water table is a substantial distance below ground level. Some water is contained in the soil in the form of perched water tables supported by clay layers.

4.2 Water Balance

The catchment area to Leixlip is 842 sq.km. This area is divided into an upper catchment of 308 sq.km to the dams at Pollaphuca/Golden Falls and a "truncated" middle catchment between these dams and Leixlip. The presence of the dams allows an assessment to be made of groundwater effects in the truncated flat area downstream.

The water balance of the Middle Liffey Catchment can be presented as follows:

$$P + GF = Q + S + AE$$

where

P = Precipitation

GF = Discharge from Golden Falls Power Station, upstream of the middle catchment

Q = Total Stream flow

S = Soil moisture change or change in storage

AE = Actual evaporation

Measurements of P, GF, AE and Q are available from the Middle Catchment. The change in storage was derived from the equation and then compared with the measured change in groundwater storage at Eyrefield.

Precipitation

Fourteen daily rainfall stations have been used to calculate the mean areal rainfall, which is calculated using the "iso-percental method".

Golden Falls Discharge (F)

The total discharge is entered each hour on the daily load report.

Total Streamflow (Q)

The stream flow is measured continuously at a gauging station at Celbridge. This flow includes discharge from Golden Falls Power Station.

Actual Evaporation (AE)

The actual evaporation is calculated from (1) the water balance and from (2) the Potential Evaporation, which is measured at Casement Airport, in County Dublin.

Soil Moisture Change or Change in Storage (S)

As the other inputs into the equation are measured this value S was derived.

An eighteen year period, 1966/67 to 1983/84, was considered in the analysis. A ten year period, 1974/75 to 1983/84 was used in the calibration and the remaining eight years in the verification.

The equation was applied for the following sets of data:

1. For the ten year period as a whole (Oct. 74 to Sept. 84).

2. Year by year (Hydrometric year, i.e. Oct. to Oct.)

3. Season by season.

The components of the equation are expressed as mm on the catchment area of 534km^2.

1. For the Ten Year Period

In Table 1 the values of the ten year period are presented.

Mean Areal Rainfall (mm)	Golden Falls Discharge (mm)	Celbridge Streamflow (mm)	Potential Evaporation (mm)
830	435	770	529

Table 1 - Ten Year Period, Annual Average Water Balance

The Water Balance Equation is applied assuming that the average change in groundwater and soil moisture storage is negligible.

$$P + G.F. = Q + S + AE$$

$$830 + 435 = 770 + O + AE$$

$$AE = 494\text{mm}$$

The Potential Evaporation (PE) for the period was measured to be 529mm per annum.

Therefore, the Actual Evaporation (AE) $= \frac{494}{529} \times 100\%$ PE

$$AE = 93.4\% \text{ PE}$$

For the purpose of this study the Actual Evaporation was therefore taken as 93.4% of the Potential Evaporation.

This value of 93.4% is around the average for the country. This indicates that there is no water lost through the Curragh aquifer to the River Barrow.

2. Year by Year

The values for the ten year period were analysed on a year by year basis. Each year, the actual evapotranspiration was assumed to be 93.4% of the Penman potential derived from records. Then the change in storage was calculated from the water balance equation.

The change in storage each year was compared with the recorded water levels in the borehole at Eyrefield.

The change in the water level at Eyrefield was very small, and the increases and decreases did not correspond to the change in storage given by the water balance equation. This would indicate that the change in storage represents the change in the soil moisture above the water table. The water table is between 20m and 25m deep at Eyrefield.

3. Season by Season

A water balance for each month was carried out. Then the average change in storage or soil moisture was calculated for each month.

Month	Average Change (mm)	Cumulative Storage (mm)
October	+43.5	+43.5
November	+27.0	+70.5
December	+50.4	+120.9
January	+26.2	+147.1
February	+ 0.7	+147.8
March	+ 0.6	+148.4
April	-31.2	+117.2
May	-33.5	+ 83.7
June	-39.8	+ 43.9
July	-54.9	- 11.0
August	-16.3	- 27.4
September	+29.0	+ 1.7

Table 2 - Seasonal Water Balance

Therefore, it can be established that recharge of the groundwater and soil moisture takes place between September and January and that a draw on the storage occurs from April to August. The high storage exhibits a plateau during February and March.

4.3 Conceptual Flood Forecasting Model

Nineteen years of records were used for this analysis. A datum value for the moisture in the soil at the end of September 1974 was taken as zero. The cumulative storage of the water within the soil, as calculated using the Water Balance Equation, relative to September 1974 was derived on a monthly basis.

The short-term percentage runoff for the floods analysed and the corresponding cumulative storage value for the beginning of the month, are presented in Table 3.

Flood Event	Observed Percentage Runoff	Cumulative Change in Storage (mm)
21-25 Feb. '67	39%	184.5
31-3 Oct./Nov. '68	20%	-166.9
21-25 Nov. '70	10%	-327.3
28-4 Oct./Nov. '77	17%	-77.2
26-29 Dec. '79	21%	-65.5
19-24 Jan. '80	28%	- 7.3
16-21 Mar. '80	27%	29.0
7-10 Dec. '83	22%	67.6

Table 3 - Short-Term Percentage Runoff and Cumulative Storage

The figures follow a logical pattern. The more moisture in the soil the larger the percentage runoff, because the infiltration rate is small. On the other hand when the moisture in the soil is relatively low then the percentage runoff is small, because the infiltration rate is large.

A line was fitted to these points using the Least Squares Method, giving the following formula:

$$PR = 25.24 + 0.0494S$$

with S = Cumulative Storage
and PR = Percentage Runoff

The measure of efficiency for the fit is 0.4. However, the prediction for the value for Dec. '83 is overestimating by 14%. If consideration is only given to the six values which have observed percentage runoffs greater than 16% then an efficiency of +0.81 is achieved. Therefore as this study was mainly concerned about the prediction of the high values, it is deemed acceptable.

A number of separate flood events were used to verify this theory for the catchment.

5. DISCUSSION

It is important to be aware of the levels of error involved in recorded data.

Rainfall is consistently higher than the observed readings would suggest; this is due to the measurement process itself. Although it is generally agreed that the error is in the order of 10% no agreement appears to be forthcoming on the adjustment of the observations. Runoff is slightly more accurate, perhaps to a few percent.

Water balance studies can be useful in determining trends and seasonal components over a period of time and the result is more accurate as the timespan increases. Six months is about as short a period over which changes in catchment storage can be reliably estimated.

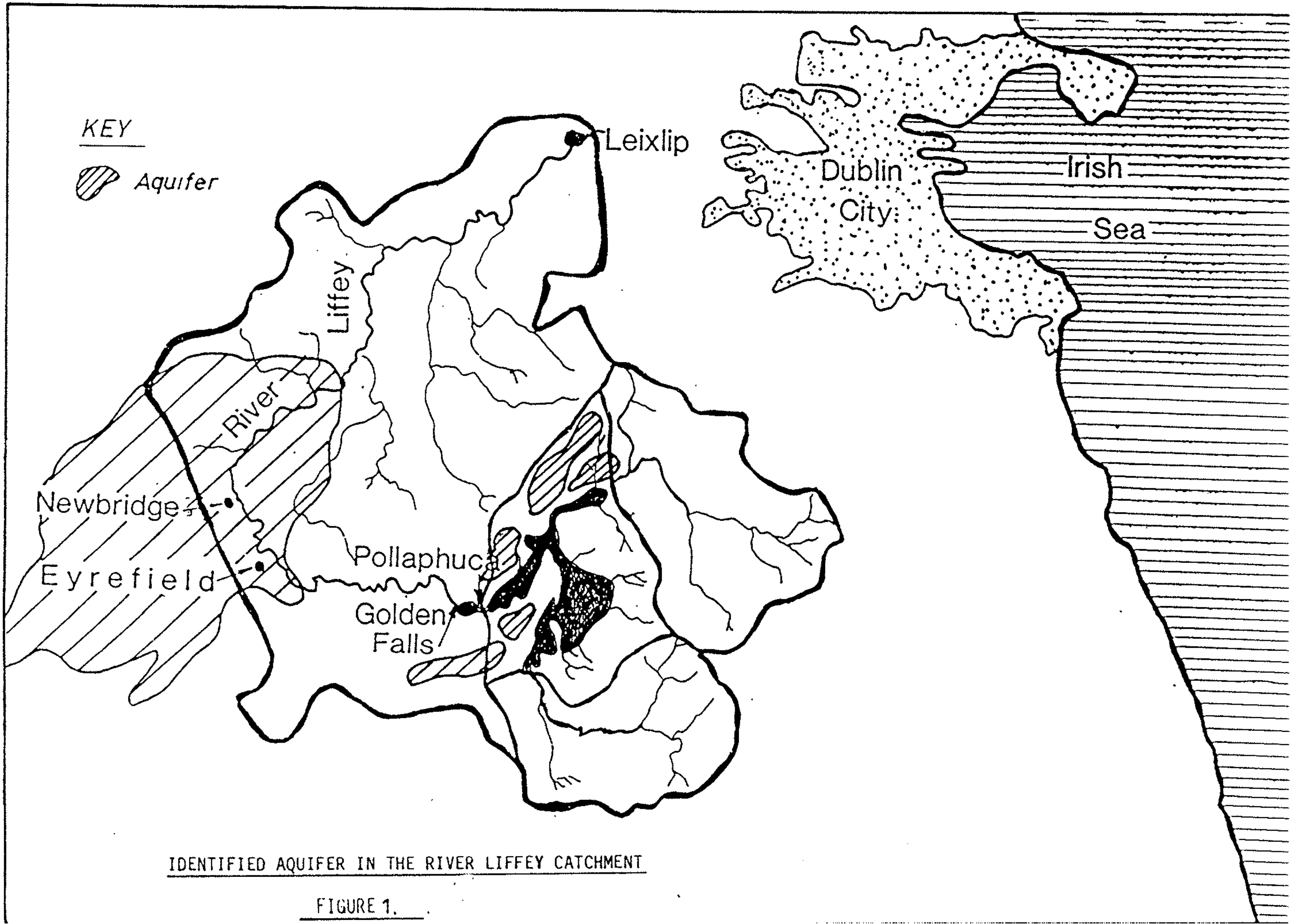
Despite these potential inaccuracies, the case studies indicate that water balance studies are useful in verifying the original data and in the investigation of groundwater effects on surface flows.

References

1. Carmody, M.J. Water Balance of the Moy Catchment
M. Eng. Sc. Thesis, NUI, 1977

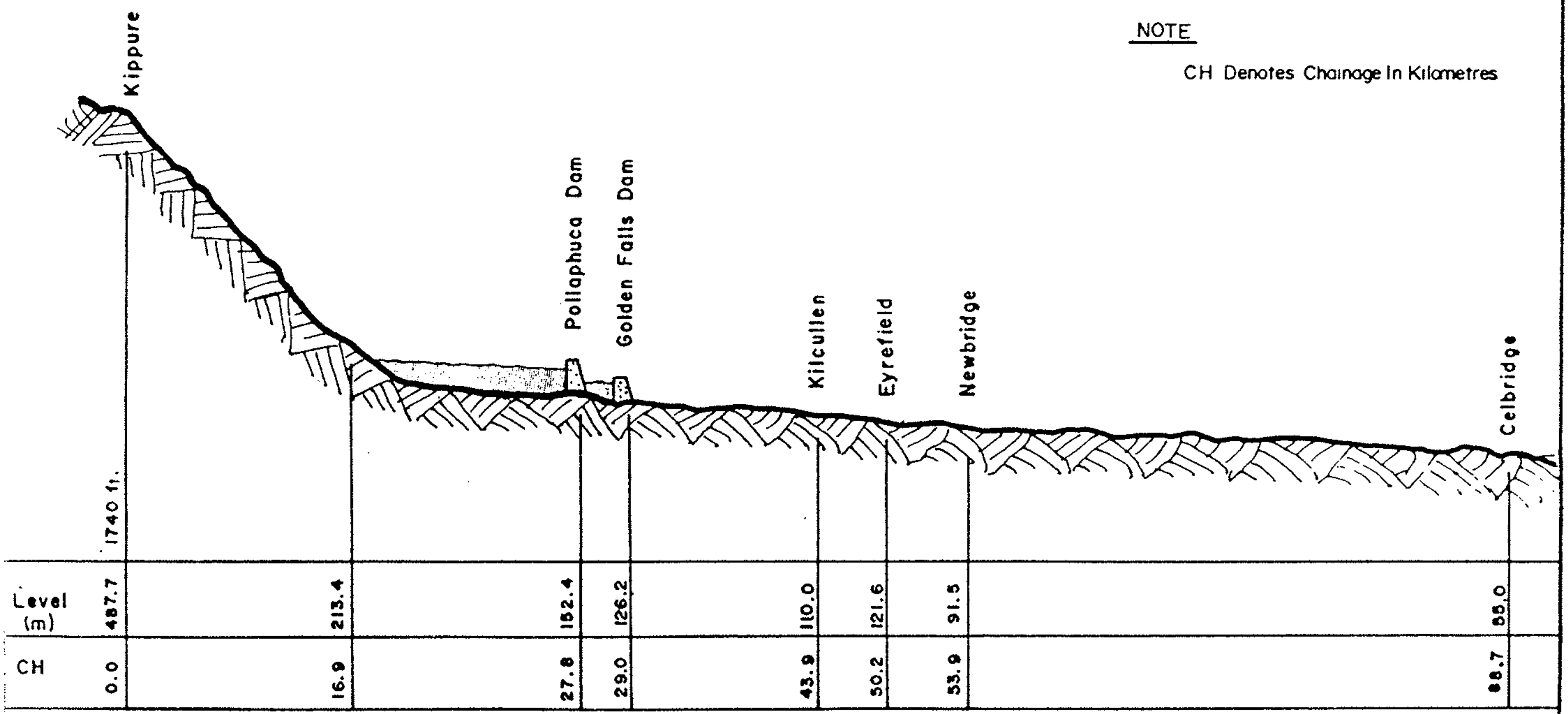
2. Lough Scur Water Balance. Internal Report,
ESB International, 1990

3. Brogan, O. Hydrological Forecasting on the River Liffey.
M.Eng. Sc. Thesis, NUI, 1986



IDENTIFIED AQUIFER IN THE RIVER LIFFEY CATCHMENT

FIGURE 1.



NOTE

CH Denotes Chainage In Kilometres

LONGITUDINAL SECTION
THRO. RIVER LIFFEY

FIGURE 2.

AN OVERVIEW OF STATUTORY REGULATIONS IN RELATION TO WATER QUALITY

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Introduction

For almost two decades there has been a continuing, though somewhat erratic as regards timing, issue of environmental quality legislation from the European Community in Brussels. The initial Directive relating specifically to water quality was the "Council Directive of 16 June 1975 concerning the quality required of surface water intended for the abstraction of drinking water in the Member States" - the so-called Surface Water Directive. This was followed on 6 December 1975 by the Bathing Water Directive.

On 4 May 1976 the important Dangerous Substances Directive was adopted and this was followed two years later by the Fresh Water Fish Directive [18 July 1978]. In 1979 two further Directives were adopted - the Shellfish [Waters] Directive on 30 October and, of prime interest in the present context, the Ground Water Directive [17 December]. Finally, to complete this initial series of Directives the Drinking Water Directive was adopted on 15 July 1980.

These Directives fall into two groups: those which lay down specific quality standards for waters intended for different uses (the majority), and those which seek to limit or prohibit the discharge of different types of pollutant or pollutant groups into the aquatic environment. The latter class comprises the Dangerous Substances and

Ground Water Directives, both of which deserve some further comment.

The Dangerous Substances Directive on "pollution caused by certain dangerous substances discharged into the aquatic environment" did not lay down quality standards for any type of receiving water. Rather, it specified in two lists [I - the so-called "Black list" - and II - the "Grey list"] those pollutant substances were to be effectively prohibited from and limited in discharge, respectively. It has been termed a "framework" Directive in that it is intended to be something of an umbrella under which many other more specific Directives could be adopted over time.

This Directive specifically excluded ground water from its scope, not because of any irrelevance but because it was envisaged that a separate Directive on the important topic of ground water would issue in due course. This follow-up, or so-called "daughter", Directive on ground water was adopted in late 1979. It followed closely, but not exactly, the lines of its parent. There were again two pollutant Lists which were very similar to those in the Dangerous Substances Directive, and once more the thrust was on emission control by the implementing authorities rather than environmental monitoring.

The main requirements of the Ground Water Directive are discussed below, along with those of the very recently adopted [12 December 1991] Directive on "the protection of waters against pollution caused by nitrates from agricultural sources." It may be mentioned for completeness that other, very detailed daughter Directives relating to specific pollutants in List I [cadmium, hexachlorocyclohexane and mercury, for example] have also been adopted in the period since 1980.

Implementing EC Legislation

There are two broad aspects of the implementation of the Community legislation, the administrative and the operational. The former includes the formal notification by the Community to the Government of the adoption of the Directive in question and, in turn, the notification of the "competent national authorities" by the Department of the Environment which has overall responsibility in such matters. For environmental Directives the relevant national implementation agencies are the local and sanitary authorities. Initially, the latter stage was carried out by the issue of a Departmental circular setting out the legislative requirements of the particular Directive and usually requesting that the data returns from such implementation operations be forwarded to the Department of the Environment which would then notify the EC Commission of progress made.

Latterly, however, in conformity with the provisions of the relevant Directives, the Minister for the Environment has made formal Regulations which bring the EC requirements specifically into Irish law. These Regulations in effect supersede the Directives to which they relate and the latter are henceforth referred to only rarely. To some extent the Regulations may be said to round off the Directives, by specifying in detail the precise quality standards which should apply in this country. An exception is the Fresh Water Fish Directive which is not completely supplanted by the Regulations made, as indicated below.

To date, The Minister has made the following Regulations in connexion with Water Quality Directives:

Directive	Regulations	Date Made	Reference
Surface Water	European Communities (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989	10/11/1989	S.I. 294 of 1989
Bathing Water	European Communities (Quality of Bathing Water) Regulations, 1988	04/05/1988	S.I. 84 of 1988
Fresh Water	European Communities (Quality of Salmonid Waters)* Regulations, 1988	18/11/1988	S.I. 293 of 1988
Drinking Water	European Communities (Quality of Water Intended for Human Consumption) Regulations, 1988	29/04/1988	S.I. 81 of 1988

* The Fresh Water Fish Directive covers waters for both cyprinid [coarse] and salmonid [game] fish but all waters designated to date, as required by the legislation, have been classed as salmonid and the Regulations cover such waters only.

The operational aspects of implementation of the above legislation consist primarily of sampling and analysis in accordance with EC-specified criteria which may be both extensive and incompletely detailed. The Regulations (and the guide-line handbooks referred to later) spell out the requirements as exactly as possibly, in order to assist the implementing authorities and make for a uniform approach to monitoring. In some cases, largely, as it happens, for Directives without accompanying Regulations, survey work on water resources or on the nature and magnitude of discharges may be required in addition to ongoing monitoring.

As the function of implementing the various pieces of legislation is assigned to local and sanitary authorities, accordingly, neither the Environmental Research Unit nor its predecessor has or had any responsibilities in this area. However, as a unit of the Department of the Environment the E.R.U. has been charged with various activities designed to support, through the Water & Sanitary Services Section of the Department, the implementation activities of the implementing authorities. Thus, the E.R.U. has prepared guide-line handbooks for these authorities which are intended to contain as much practical advice and comment in the implementation of the Drinking Water and Surface Water Regulations as is practicable.

In addition, the E.R.U. has undertaken the task of analysing and collating the considerable body of data gathered by local/sanitary authorities in their implementation of the Regulations on Drinking and Surface Waters. The Minister for the Environment stated that reports on the findings of the sampling and analysis carried out under the Regulations would be published and in 1991 the first such report [covering Drinking Water in the year 1989, the first in which the local authorities undertook the formal implementation of the recently made Regulations] was published in both summary and extended forms.

The corresponding report for 1990 is nearing completion, and it is hoped that future reports will issue within a shorter period of the completion of a year's monitoring. To help achieve this objective, a computer data entry/handling package designed specifically to deal with the data requirements of the different Regulations is being provided by the E.R.U. to all bodies concerned.

The Ground Water Directive

A notable feature of the Ground Water Directive (and its parent on dangerous substances to the aquatic environment in general) is that the extent of the pollutant range encompassed in Lists I and II is potentially without limit. However, while it is totally impractical to use general monitoring as a means of implementation [the list of potential determinands and the costs of their determination does not bear thinking about!], the Directive is a very useful tool for the control of emissions of pollutants selected on a priority basis. Used in conjunction with related specific daughter Directives [e.g. cadmium], which do contain quality standards for both the discharge and the receiving water, the Ground Water Directive enables authorities to limit the emission of noxious matter.

The principal obligations of the Ground Water Directive on Member states are that they shall

> prevent the introduction into ground water of substances in List I and limit the introduction into ground water of substances in List II,
>
> prohibit all direct discharges of substances in List I, subject to prior investigation any disposal or tipping for the purpose of disposal any List I substances where such action might lead to indirect discharge,
>
> make subject to prior investigation all discharges of substances in List II, so as to limit such discharges,
>
> investigate the disposal or tipping for purpose of disposal of List II substances which might lead to indirect discharge,
>
> and take the appropriate measures they shall deem necessary to limit all indirect discharge of substances in List II, due to activities on or in the ground other than those exempted.

There is little to be added to the above except to note that while no Regulations have so far been made this is not to imply any lack of importance to the discharge of pollutants to ground water. Indeed, the adoption of the Nitrates Directive, discussed next, underlines this point. It may well be in the case of the Ground Water Directive that the broad coverage of its Lists and the fact that the potential emissions will vary greatly from authority area to authority area would make the framing of concise Regulations a matter of some impracticability.

The Nitrates Directive

The principal requirements of this important Directive are as follows:

waters affected by pollution and which could be affected by pollution unless protective measures were taken must be identified by Member States according to specified criteria [see below]

Member States must designate as vulnerable zones all lands which drain into the waters identified as above

Member States must establish codes of "good agricultural practice" and where necessary set up programmes promoting the application of these codes

action programmes must be established in respect of designated vulnerable zones, taking into account available scientific and technical data as well as local environmental conditions

monitoring must be undertaken in order to assess the effectiveness of such action programmes.

Specific, immediate requirements of the Directive are that the nitrate concentration must be monitored for a period of one year, "at least monthly and more frequently during flood periods" at both surface water and ground water stations. The former should be as prescribed by the Surface Water Directive or at "other sampling stations which are representative of surface waters of Member States", while the latter must be "representative of the groundwater aquifers of Member States" and should be monitored "at regular intervals and taking into account the provisions of [the Drinking Water] Directive 80/778/EEC."

Further significant obligations are the need to repeat this monitoring every four years (unless the nitrate level in all earlier samples was below 25 mg/l NO3, in which case monitoring every eight years will suffice) and to "review the eutrophic state of...fresh surface waters, estuarial and coastal waters every four years." A point of technical interest is that the specified reference methods of analysis "shall be used." This is in contrast to earlier Directives where the choice of method was left to the analyst, provided always that methods chosen gave the same degree of performance as the stated reference methods.

The criteria for the "identification" of waters [as explained above] are of interest:

"A. Waters...shall be identified making use, inter alia, of the following criteria:

1. Whether surface fresh waters, in particular those used

or intended for the abstraction of drinking water contain, or could contain, if action...is not taken, more than the concentration of nitrates laid down in accordance with [the Surface Water] Directive 75/440/EEC;

2. Whether ground waters contain more than 50 mg/l nitrates or could contain more than 50 mg/l nitrates if action...is not taken;

3. Whether natural freshwater lakes, other freshwater bodies, estuaries, coastal waters and marine waters are found to be eutrophic or in the near future may become eutrophic if action...is not taken.

B. In applying these criteria, Member States shall also take account of:

1. The physical and environmental characteristics of the waters and land;

2. The current understanding of the behaviour of nitrogen compounds in the environment (water and soil);

3. The current understanding of the impact of the action taken pursuant to Article 5."

Conclusion

Clearly, the Nitrates Directive has an important place in the body of legislation reviewed briefly here. Its adoption is timely as, although excessive levels of nitrate are not commonly encountered in either surface waters or the drinking waters derived from them, there are occasional occurrences of levels of 60, 70 or 80 mg/l NO3 in small water supplies - private wells - throughout the country. Often, such supplies are also heavily contaminated with faecal coliforms, confirming that measures intended to reduce pollution from agricultural sources are very appropriate in rural Ireland.

Summarising the above legislation as a body, it emerges that there is a good mechanism for the protection of public health, in particular, with quality standards being imposed on raw and final drinking waters, and emission standards applying to a wide spectrum of noxious pollutants. Perhaps the only apparent uncrossed "t" is the absence to date of standards for ground water intended as drinking water. However, such standards may be quite impracticable to impose and to monitor without a great effort. For the present, the consumer may be content that adherence to the drinking water standards affords a very high degree of protection of health.

MICROBIOLOGICAL ASPECTS OF GROUNDWATER QUALITY

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Paper presented to 12th Annual International Association of Hydrogeologists' (Irish Group) Seminar on 'Groundwater and Regional Water Supply', Portlaoise, 7th and 8th April, 1992.

The Nature of Microorganisms

Microorganisms occur in the Kingdom Protista, which includes bacteria, cyanobacteria (formerly blue-green algae), fungi, yeasts, algae, protozoa and viruses.

Bacteria and cyanobacteria do not contain a nucleus and are very small - 1-10 microns. Fungi, yeasts, algae and protozoa contain nuclei, are much larger - >10 microns -, and are typically multicellular. Viruses are not true cells but are parasitic on all cell types and are extremely small, in the nanometer range. Bacteria and viruses pose the greatest threat to groundwater quality and are responsible for causing a range of ailments including, gastroenteritis, gas gangrene, salmonella poisoning, polio and hepatitis.

This paper is concerned primarily with bacteria in groundwater.

The Microbial Ecology of Groundwater

The microbial ecology of groundwater, particularly uncontaminated groundwater, is poorly understood because *in situ* studies are almost impossible to carry out and aseptic sampling is very difficult.

Because groundwater contains a range of dissolved salts that are derived from both the recharging rainfall and from reactions between the water and the soil, subsoil and rock, there is a nutritional base for a microbial population. However, some physical conditions, e.g. low temperatures and the absence of oxygen may be limiting. Likewise, the lack of sources of carbon - which are required as an energy source - may restrict microbe development. Where groundwater contamination takes place the microbial population dynamics change because biodegradeable organic material or growth stimulating inorganic compounds are introduced.

In general, under non-polluted conditions groundwater contains low numbers of bacteria that are non-pathogenic to man.

The Plate Count Method

The plate count method involves serially diluting the sample in a diluent solution such as Ringer's solution or a standard saline solution from which 1 ml aliquots are transferred to empty sterile petri dishes. Molten sterile agar is introduced to the petri dishes which are then allowed to set and incubated. After incubation colony forming units are counted (cfu's).

The Multiple Tube Method

The multiple tube method, which is also know as the 'most probable number' method involves the introduction of specific volumes of sample into a series of tubes containing a broth medium. The method involves determining the number of cfu's based on the presence or absence of organisms from aliquots of different sizes.

The Membrane Filtration Method

The membrane filtration method is the simplest and most commonly used method in bacteriological water analysis. The method involves the use of a sterilizable filtration apparatus into which is placed a cellulose acetate membrane filter. Following filtration of the sample the filter is transferred onto a growth medium and incubated. Following incubation the colonies are counted and the cfu's $100ml^{-1}$ are determined.

Bacteriological determinations that are commonly undertaken in water and wastewater samples are total viable aerobic bacteria, coliforms and faecal streptococci. Determinations for sulphite reducing *Clostridia* spp. and *Salmonella* spp. are undertaken less frequently.

Total Viable Aerobic Bacteria

The total viable aerobic bacteria determination, also referred to as 'total plate count' or 'total mesophylls' is carried out using the plate count method. It is carried out at incubation temperatures of 22°C (for 24 hours) and/or 37°C (for 48 hours) (to avoid overgrowth). It is a routine test in the USA but not in the UK. It is a useful to test to indicate the size of the bacterial population in a sample but there has been the tendency to attach a degree of importance that is not warranted by the test's technical or statistical accuracy.

Coliforms

Two tests for coliforms are usually carried out; Total coliforms and faecal coliforms. The multiple tube and membrane filtration methods are the methods routinely used for these two

However, the ratio has many limitations, most notably results often fall between the extremes, and thus make interpretation difficult, and the organisms may have different survival times.

Sulphite Reducing *Clostridia* spp.

The sulphite reducing (they are anaerobes) *Clostridia* occur naturally in the soil and in the intestines of man and other higher animals. Many species within the genus are pathogenic; the most frequently encountered organism is *Clostridium perfringens* which causes food poisoning and gas gangrene in wounds. The organisms are spore formers and are more resistant to adverse environmental conditions. If encountered in a sample they suggest contamination at a remote time.

Salmonella spp.

All strains of this group of organisms are pathogenic, being responsible for food poisoning, enteric fever and septicemia. They are commonly isolated from animal faeces and occasionally from infected animals' urine and blood.

Salmonella spp. are absent from unpolluted waters but even in polluted waters the numbers present will be low, if they are present at all, and it is thus necessary to analyse a large volume of sample.

It must be stressed that suitable training is necessary to safely carry out microbial analysis and to handle microbial cultures. Many of the problems that arise in the interpretation of microbiological results occur because of incorrect sample collection and handling, incorrect media preparation and inadequate aseptic technique.

Groundwater Microbiology Standards

The Council Directive of 15 July 1980 relating to the quality of water intended for human consumption (Official Journal of the European Communities No. L229/11) lays down the standards required for the microbiological quality of drinking water. It should be stressed that these are for 'drinking' water, i.e. following treatment, and not for 'raw' water. This implies that untreated groundwater samples which just fail to meet the microbiological standards but which are chemically adequate may well be suitable for treatment by, for example, UV radiation..

The table below shows the microbiological standards required in drinking water.

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After working in Germany in the photographic manufacturing industry he returned to Ireland to spend five years in the State Laboratory before moving to An Foras Forbartha in 1978 to concentrate on organic pollutants in water.
He has maintained his interest in this area in the new Environmental Research Unit which was set up in 1988.
The paper covers work on one group of these compounds.

TRIHALOMETHANES IN DRINKING WATER

Ciaran O'Donnell

Environmental Research Unit.

Introduction

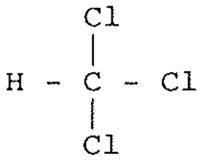
Since the late 1960's there has been a growing interest in the individual organic chemicals present in water. Because these were found at levels far below the traditional inorganic ions such as chloride and nitrate, they are often referred to as organic micropollutants.

Guidelines for the control of micropollutants have been formulated by national and international bodies such as the United States Environmental Protection Agency, the World Health Organisation and the Commission of the European Communities.

One group of organic micropollutants that has been the subject of widespread investigation (1,2,3) is the so-called trihalomethanes. The conditions for their formation during potable water treatment have been studied and are widely found in Ireland i.e. chlorination of surface water containing humic material. This paper deals with work from 1981-1988 on trihalomethanes in Irish water supplies.

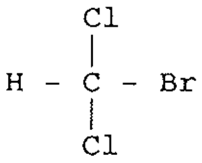
The Background

The trihalomethanes [THM] are a group of compounds formed during chlorination of water. They are related structurally to methane (CH_4) by the substitution of three of the four hydrogen atoms with atoms of chlorine and bromine. The latter are the most common members of the elements known as halogens, hence the term "trihalomethanes".



$$\mathrm{H - \overset{Cl}{\underset{Cl}{C}} - Cl}$$

Chloroform



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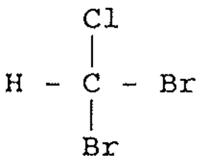
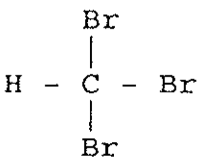
Bromodichloromethane



$$\mathrm{H - \overset{Cl}{\underset{Br}{C}} - Br}$$

Dibromochloromethane



$$\mathrm{H - \overset{Br}{\underset{Br}{C}} - Br}$$

Bromoform

The Formation of Trihalomethanes

Trihalomethanes are formed by the oxidising action of chlorine on the dissolved organic matter in raw water. Humic acid appears to be the main precursor material for this reaction. The brominated compounds are produced when bromine becomes involved in the reaction, displacing some chlorine atoms. This normally leads to only one bromine atom per molecule, but where more bromine is available a second chlorine atom may be displaced in a small proportion of the monobrominated species. Likewise, even smaller quantities of the tribromo compound may be formed by the further action of bromine. This sequential production may be represented as follows:

Organics ---> $CHCl_3$ ---> $CHCl_2Br$ ---> $CHClBr_2$ ---> $CHBr_3$

The highest level of bromoform observed in this study -almost 9ug/l-was from a coastal region, possibly reflecting the a marine influence.

Trihalomethanes account for approximately 10% of the total organic chlorine content of drinking water. Their presence therefore gives an indication of the occurrence of other very diverse compounds in the water. For this reason an analysis for THM gives both specific information on the concentration of these four compounds and more general information on the presence of further unidentified compounds. It also provides an indication of the overall organic content of the raw water. While there is no specific toxicological information available on the many unidentified chlorinated compounds, it is generally accepted that they are undesirable and that their presence should be minimised.

Toxicity of Trihalomethanes

Chloroform has been widely used as a laboratory solvent for many years. Besides its first use as an anaesthetic in 1847, it has been used as an ingredient in cough mixtures and other pharmaceutical preparations. However, in 1976 the U.S. Food and Drugs Administration banned the use of chloroform as an ingredient in human drug and cosmetic products. This move followed its classification as a carcinogen (1) and it raised the question of the risks associated with the general exposure of the population to chloroform from other sources, including drinking water.

The three brominated trihalomethanes have been found to be mutagenic in tests and are therefore included in the parameter "total THM".

Drinking Water Limits

Trihalomethanes were first reported in drinking water by Rook in 1974 (2) and they have since been found in almost all chlorinated supplies examined. A survey of 80 U.S. cities for the Environmental Protection Agency published in 1975 (3) reported that THM were found in 79 of the water supplies at levels ranging from 0.1 to 311 ug/l. In 1979 the E.P.A. set a limit of 100 ug/l for total THM in finished drinking water (4). The World Health Organisation in its Guidelines for Drinking-Water Quality (1984) (5) sets no level for trihalomethanes as a group but has recommended a limit for chloroform of 30 ug/l.

There is as yet no specific level prescribed for THM in European drinking waters, but the E.E.C. Directive on Water for Human Consumption (6) mentions THM under "other organochlorine compounds" (Parameter No.32) and recommends that they should be kept "as low as possible". The guide level for this group as a whole is 1 ug/l which, however, is not realistic for THM as these compounds are present in all chlorinated surface waters in concentrations of several microgrammes per litre at the very least. This situation is currently under review.
The Irish regulations issued in 1988 (7) set a maximum admissable concentration of 100 ug/l for this parameter.

Measurements in Ireland

Preliminary analyses of THM in drinking waters showed that all chlorinated supplies examined, with the exception of those based on groundwater sources, contained chloroform and bromodichloromethane at levels in the microgramme per litre range, with occasional traces of the two heavier compounds.

While it is difficult to assess the importance of THM in potable chlorinated waters, their presence does indicate the possible occurrence of undesirable complex halogenated matter. Some knowledge of the present position is therefore highly desirable. It was this need for background information from a range of Irish water supplies which motivated the preliminary survey under discussion in this paper. The aim of the study was to estimate the extent to which THM occur in Irish drinking water supplies. The data are dealt with as a whole in order to provide an overview of the situation. Due to the many variable factors involved in the formation of THM, each supply is unique and no broad solutions for dealing with excessive values are therefore proposed.

Sampling

It is important to ensure that the concentrations of THM in a sample once taken do not alter in the period between sampling and analysis. A preservative (sodium thiosulphate or ascorbic acid) is usually added to the water samples immediately after they are taken. This has the effect of neutralising any residual chlorine present in the sample, preventing the formation of further THM before the analysis can be carried out. Losses of THM, on the other hand, can be prevented by ensuring that there is no free headspace in the sample container into which they could escape.

Observations have established that variations in THM concentrations in the actual supply do not occur over short periods and that there is little significant change over a working day. Variations in the chloroform and total THM content of two supplies with different THM levels are shown in figures 1 and 2. The results shown in figure 1 are from a domestic supply which was sampled at two-hourly intervals from 08.00 to 24.00 hours.

Figure 2 shows results from a laboratory tap, sampled every two hours from 10.00 to 16.00 hours. In both figures the smaller bar

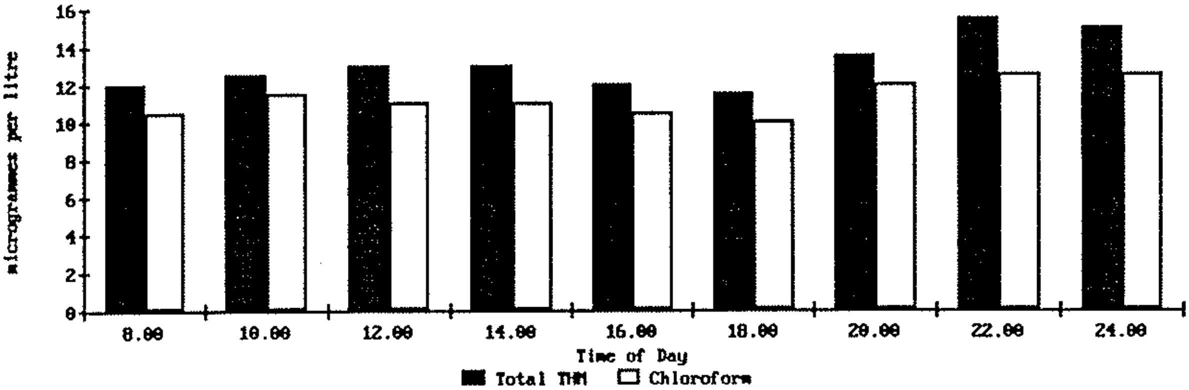


Figure 1. Short-term variations in low THM and Chloroform levels

shows the chloroform level while the larger one indicates total THM, and it can be seen that in waters with higher chloroform content the three brominated compounds can make a significant contribution to the total figure.

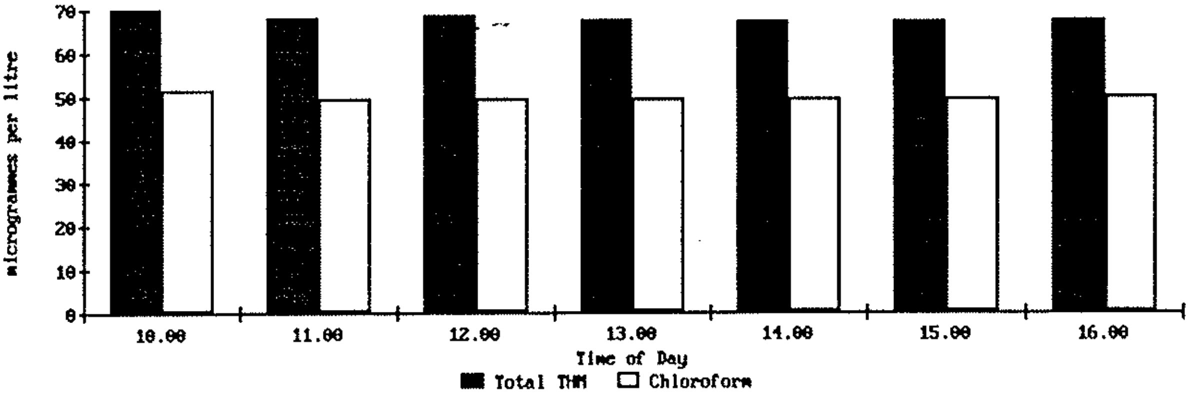


Figure 2. Short-term variations in moderate THM and Chloroform levels.

From day to day, and even over a period of years, the levels of THM in a relatively clean supply (10-30 ug/l) were also found to be quite stable (Figure 3). This graph is based on levels found in the laboratory tap water from mid-1982 to the end of 1986. The total variation in THM level from about 3 ug/l to 19 ug/l shows great stability; in fact, the greatest variation only occurred in the last six months of this study.

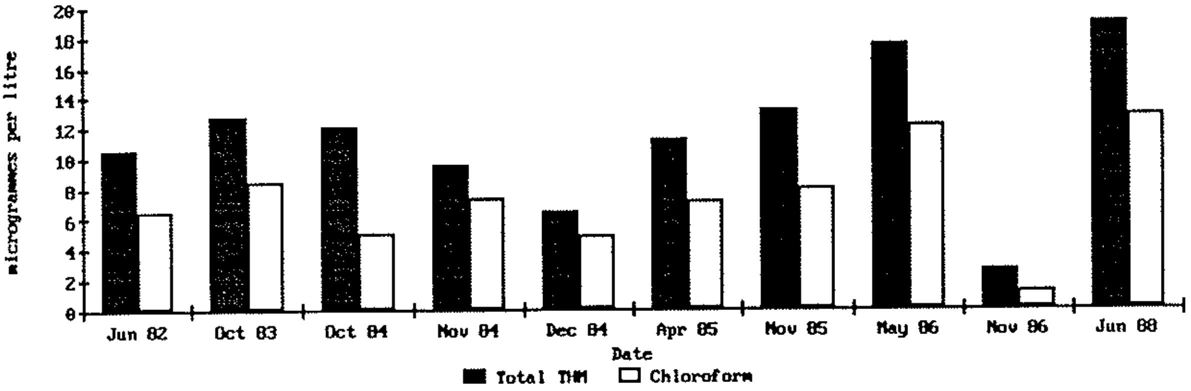


Figure 3. Long-term variations in THM and Chloroform levels

These results show that time of day is not important in sampling for these compounds and when two samples taken on different days give similar results, they represent the typical level of THM for a given supply.

Analysis

Analysis of THM is done by gas chromatography with electron capture detection (GC/ECD). The THM must be separated from the water before injection to prevent errors due to formation of further THM in the heated injection area. This can be done by purge and trap methods or by solvent extraction. Both methods were used for the preliminary work but the purge and trap system is quite slow and has been discontinued.

The GC analysis must be confirmed on a second column and this has now been developed into a simultaneous operation using a dual column system (8). In this system each compound produces two peaks in a fixed ratio to give confirmation of its correct identification as well as its concentration.

Results

A total of 394 water samples from 140 supplies were analysed up to mid-1988. Where possible, two samples were taken from a supply, but all available data were included in the analysis below. The results were sorted and the frequency of occurrence was plotted against the levels found for each compound.

The distribution for Total THM is shown in Figure 4 and it can be seen that while 222 individual samples had less than 20 ug/l, all of the others contained easily measurable quantities of THM. The median value was just under 17ug/l.

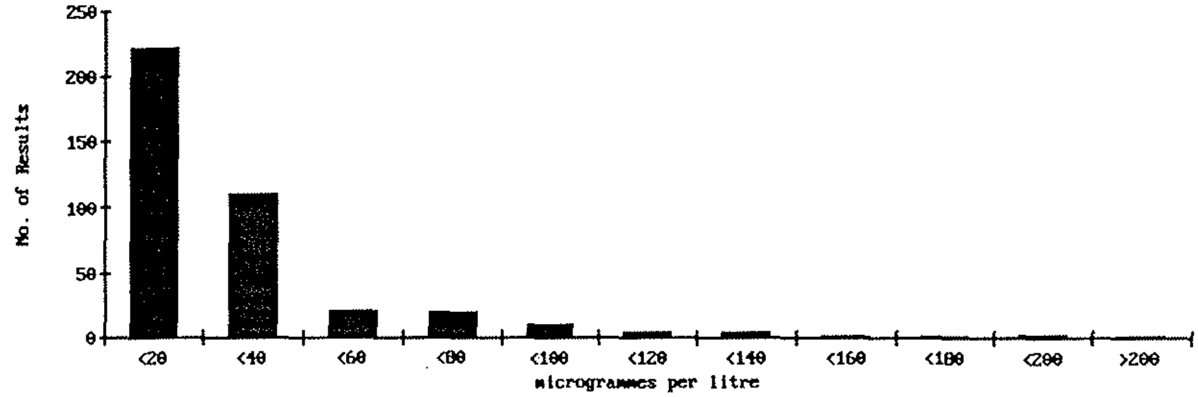


Figure 4. Frequency distribution of THM levels.

The histogram in Figure 5 shows that 308 samples or 78% contained less than 20 ug/l of chloroform. Many of these were taken from small groundwater sources, and it appears that all of the surface water sources examined contained sufficient precursor material to produce measurable levels of chloroform. The median values found for the four individual compounds were, Chloroform 9.9ug/l, Bromodichloromethane 4.3ug/l, with Dibromochloromethane and Bromoform both less than 1ug/l.

Conclusions

From these initial findings it is clear that trihalomethanes are present in many chlorinated water supplies. This should be viewed in the light of the long and successful history of chlorination as a water treatment process. Nevertheless, in view of the fact that the supplies most affected can be easily identified, some investigation of the possibility of remedial action should be undertaken in these cases.

Some remedies can be both simple and effective. In one exceptional case, a supply with a THM content of over 110ug/l was found to be pre-chlorinated before the clarification step. This allowed maximum contact between precursors and chlorine with the resulting high THM level. After investigation of the situation, the pre-chlorination step was omitted and the THM content of the finished water dropped to less than 15ug/l.

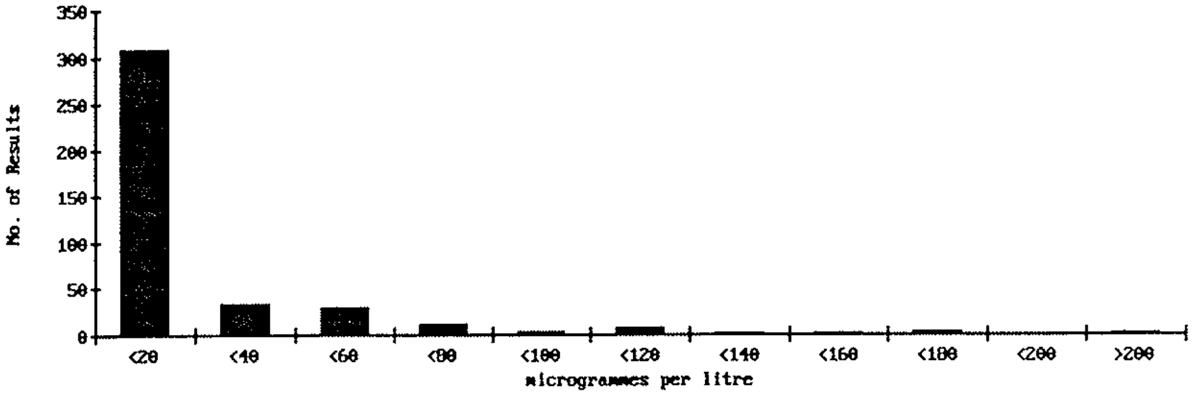


Figure 5. Frequency distribution of Chloroform levels.

The results of this investigation have shown that trihalomethanes are present at measurable levels in Irish drinking water supplies. A more structured survey is now underway to assess the position countrywide.

References

1. International Agency for Research on Cancer. "Some Halogenated Hydrocarbons", IARC Monographs, Vol. 20, Lyon, 1979, p.417.
2. Rook, J.J., "Formation of Haloforms during Chlorination of Natural Waters.", J. Water Treat. Exam., 23 (1974) 234.
3. Symons, J.M., Bellar, T.A., et al., "National Organics Reconnaissance Survey for Halogenated Organics," J. Am. Water Wks. Assoc., 67 (1975) 634.
4. U.S. Environmental Protection Agency. National Interim Primary Drinking Water Regulations. "Control of Trihalomethanes in Drinking Water; Final Rule", Fed. Reg., 44 (231), 68624 (1979).
5. World Health Organisation, "Guidelines for Drinking Water Quality," W.H.O., Geneva (1984).
6. E.E.C. Council Directive 80/778/EEC (15 July 1980) Relating to the Quality of Water Intended for Human Consumption, [O.J.,No.L229, 30.8.1980, p.11.]
7. European Communities (Quality of Water Intended for Human Consumption) Regulations, 1988. S.I.No.81 of 1988, Stationary Office, Dublin.
8. O'Donnell C., O'Donnell M., "Dual Column Chromatography in a Standard Gas Chromatograph", Proceedings of the sixth European Symposium on Organic Micropollutants in the Aquatic Environment held in Lisbon (Portugal), May 22-24, 1990, A.Bjorseth and G.Angeletti (eds.), Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 306-310.

INTERPRETATION OF A "TYPICAL" WATER ANALYSIS

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Presentation to the annual meeting of the International Association of Hydrogeologists, 1992.

1. Scope of presentation.

Since this seminar has been organised by the IAH and since the principal interest of the Association is groundwater, the scope of this presentation is limited to the chemical analysis of groundwater. Therefore there will be little comment on parameters typically determined on surface waters, effluents, sludges etc. These parameters are commonly biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (s.s.), fat, oil and grease (FOG) etc. As a general rule these parameters are not "sensitive" enough to detect contamination of groundwater unless it is a case of very severe pollution.

Interpreting a typical water analysis involves more than just examining the numbers on a sheet of paper. The following three sections discuss in outline a number of aspects which have to be taken into consideration as well as the actual numbers if an adequate conclusion is to be reached about the results.

2. What is a water analysis ?

A chemical analysis is a sheet of paper stating the results of the analysis for various parameters. In the extremes the analysis could be just a pH measurement or if resources (staff, time, cash and equipment) were unlimited, it could comprise thousands of parameters ranging from the humble pH to the sophisticated (relatively) organochlorine pesticide.

The analysis most people will be familiar with is sometimes called a standard analysis and includes the parameters listed in Table 1.

Table 1: Parameters of a typical standard analysis.

pH
Colour
Turbidity
Electrical Conductivity
Total Organic Carbon
or
Permanganate Value

Total Hardness
Total Alkalinity
Chloride
Sulphate
Nitrate

Calcium
Magnesium
Sodium
Potassium
Iron
Copper
Manganese
Zinc
Lead

Nitrite
Ammonium

However, if one looks at the Drinking Water Regulations (S.I. No. 81 of 1988) one sees immediately that some 47 odd chemical parameters are listed and <u>all</u> of these have attached maximum concentration limits. Indeed closer inspection shows that for some parameters (PAHs and pesticides) reference compounds are listed. Absence of the reference substance in a sample does not mean that, for example, all pesticides are absent.

The reality is that there is no such thing as a "complete" analysis - the nearest we can get to it in practical terms is an analysis that reports the results for all prescribed parameters in a legally enforceable specification such as in the various EC directives. This approach breaks down when we look at the Natural Mineral Water directive (80/777/EEC) of July 1980, where not alone are there no limit values but the requirements for analysis are so vague that regulatory body (NSAI in Ireland) discretion is wide.

Finally, there is the vexed question of analytical detection limits. Different techniques often have different detection limits for the same parameter. The criteria should be a method that detects the analyte at 5 - 10 times below any specified maximum parameter concentration limit. Unless there is a technical reason for it, there is little merit in producing results orders of magnitude below a stipulated concentation limit. For example, the Drinking Water limit for manganese is 20 μg/l as Mn and most modern methods of analysis can get down without great difficulty to 5 μg/l Mn. However, I recently saw an analysis where the result was stated as 0.01 μg/l Mn. Other than show how clever the analyst was or how modern the analytical instrument was, is the result of any more value than one obtained by conventional means ?

3. What is the purpose of the analysis ?

Groundwater is used for a variety of purposes in Ireland. Some of the more important are listed in Table 2.

Table 2: Some uses of groundwater.

Human Consumption	Local Authorities	
	Group Schemes	
	Private	(householders
		(industrial
		(commercial
Fish Farming	Private	
Process, Industrial	Private	
Cooling, Industrial	Private	
Boiler Feed, Industrial	Private	
Cleaning, Industrial	Private	

Table 3: Parameters for Cooling Water Analysis

- pH
- Total dissolved solids (TDS)
- Silicon
- Total hardness
- Total alkalinity
- Chloride
- Sulphate
- Iron
- Manganese
- (Legionella pneumophila - a bug !)
- Temperature

It should be obvious that when assessing an analysis, the use or proposed use of the water must be the overall guiding factor. Reference has already been made to the

Drinking Water Regulations and its list of 47 chemical parameters. In the case of cooling water there are no regulations to be observed and a "complete" analysis would include the parameters listed in Table 3.

In the case of fish farming, parameters such as zinc, copper, dissolved oxygen etc., are of great importance.

Industrial water users often have expensive specialised items of production or associated plant where the supplier has a water quality specification. Frequently the specification is because of the risk of deposit or scale formation on heat exchanger surfaces and, growing in frequency, a specification may be designed to protect the materials of fabrication from corrosion.

In summary, the purpose if the analysis will nearly always determine the parameters to be determined and care should be taken to ensure that no relevant parameter is omitted. A good example of a parameter that is not listed in EC (and perhaps all other water quality specifications) directives is the fouling or silt density index (SDI). However, the SDI is an essential indicator of quality where water is to be treated by reverse osmosis, ultra filtration and to a lesser extent ion exchange.

4. How reliable are the results ?

A few years ago a straight forward water sample was distributed to a large number of laboratories in the U.K. The collated results horrified the circulating authority particularly since the parameters to be determined were simple and most of the laboratories were well known, reputable and employed qualified staff. Even now it is still a matter of concern that laboratories participating in external quality control schemes often get it wrong. The question arises "how many of their actual real work results are wrong ?" Quite often it is not small errors that arise but large ones where the results are out by factors of ten or twenty.

Any laboratory that values its reputation will either have or is about to put in place a quality assurance system of some sort. In the case of EOLAS the entire organisation will be registered to IS/ISO 9000 within a relatively short time. In addition, the analytical departments will be ILAB accredited. Some have already achieved this. It is notable in recent times that companies who require analytical services and who are registered to IS/ISO schemes themselves, are begining to insist that external laboratories are also registered or have a formal recognised quality assurance programme in operation.

There are a number of individuals offering a water analytical service throughout the country. Their rates are always lower than the established known laboratories (public and private sector) but all that can be said is that you get what you pay for. Throwing a bit of business to "Joe down the road" could turn out to be a very serious decision if a large capital investment is based on the results goes wrong.

5. What do the results mean ?

What do all the numbers mean when you have a set of them in front of you. The most common type of assessment will be to determine potability or compliance with the Drinking Water Regulations. The logical first step is to see if there are any exceedances. An inexperienced assessor might well conclude that everything is perfect just because no maximum limit is exceeded but this could be far from true in the case of groundwater.

It should be remembered that the Regulations apply to all sources of Drinking Water - not just groundwater. Rivers or lakes have different characteristics and the Regulations take account of these. Two simple examples will illustrate the point. The MAC (maximum admissible concentration) for colour is 20 units. A drinking water with a colour of 15 units is satisfactory if the source is a river but alarm bells should ring loudly if the source is groundwater. At the very least it may mean that surface water can gain easy access to the aquifer and some might argue that it is not true groundwater because of this. The MAC for chloride is 250 mg/l as Cl; a groundwater containing this concentration would almost certainly be seriously contaminated.

EOLAS has been involved in water analysis for the past twenty years. The comments that follow are based on an examination of the data accumulated. There is no claim that the comments are totally comprehensive and you can be certain that you will have experienced some exceptions to what is stated in the presentation.

pH

Over 95% of samples have a pH within the range 7 to 8.5 The average is 7.6. The majority of results outside the range have values less than 7 and the bulk of these are for waters drawn from sandstone, sand/gravel and volcanic rock type aquifers. The pH can be as low as 5 depending on the concentration of carbon dioxide gas and the bicarbonate-carbonate equilibrium. Values of less than 5 occur occasionally and should be regarded as suspicious and indicating a condition that should be investigated.

Colour

As noted above the colour of groundwater should be negligible and indeed colour is one of the main characteristics that distinguishes groundwater from surface water. 92% of groundwater samples analysed by EOLAS over the past five years have had a colour of less than 5 units.

There are some high yielding springs in the west that frequently exhibit colour. For example, Ballyhaunis's supply is pumped from a large natural spring on the outskirts of the town on the Clare Road. After heavy rainfall the water becomes coloured (about 20 units) and bacterial counts increase for a few days. This suggests that there is rapid infiltration of surface water to the aquifer and since the area is covered by extensive bogs containing high concentrations of humic materials the colour increases.

Colour in groundwater may also be due to ingress of surface water to a borehole or well where the liner or grouting is inadequate or defective.

Turbidity

Finely divided suspended matter, often colloidal in nature, e.g., clays and silts, gives rise to turbidity which is a cloudiness or opaqueness in water. Large rapidly settleable solids, e.g., sand grains do not contribute to turbidity but cause interference in the test. Iron that has oxidised is a common cause cause of turbidity.

A properly developed groundwater source should have negligible turbidity i.e., less than 0.2 nephelometric turbidity (NT) units. If the water becomes turbid it should be regarded as a warning sign; perhaps the well screen has failed or more commonly, surface water is gaining access. Newly developed bores will always have some turbidity until all of the fines have been pumped out

Electrical Conductivity.

The electrical conductivity is a measure of all of the dissolved ionic substances present in the water. Calcium, magnesium, sodium, bicarbonate, chloride, sulphate etc., all contribute to the conductivity. Irish groundwaters typically show a range from 150 up to 1200 μS/cm at 20 °C. The majority of samples analysed by EOLAS have a value between 400 and 650 μS/cm. This reflects the fact that a very large number of samples were drawn from limestone aquifers with consequent appreciable concentrations of calcium and bicarbonate.

Low mineral content waters have low conductivities often around 150 to 200 μS/cm. Some waters from the Cavan-Monaghan area have levels of about 1000 to 1200 μS/cm due to high levels of calcium and sulphate. In some coastal areas high values due to sodium and chloride occur particularly in the shallower aquifers (see comments on sodium and chloride below).

Values exceeding about 1200 μS/cm should be regarded as suspicious and an indication that the groundwater is being contaminated or in coastal locations as a sign of salt water intrusion.

Electrical conductivity is a useful parameter for semi-continuous monitoring of groundwater since the natural variation from season to season would not be expected to show wide swings as is the case with many surface waters. Since conductivity is due to the dissovled ions it follows that these should not show much variation either.

Calcium and Magnesium.

Calcium concentrations vary from as low as 10 mg/l to as high as about 200 mg/l as Ca. In contrast the variation in magnesium is much smaller; minimum values are around 1 mg/l and the maximum that EOLAS has recorded is 45 mg/l as Mg. The average is around 9 mg/l Mg. The sum of the calcium and magnesium approximates to the total hardness and this is conventionally expressed as mg/l as $CaCO_3$.

The most important aspect of these two cations from an assessment standpoint is to ensure that the concentrations are consistent with the geology and that there is no marked seasonal variations. Neither parameter usually changes much as a result of contamination and are therefore of very limited use in this regard.

Sodium and potassium.

Sodium varies from about 6 to 20 mg/l as Na in most Irish groundwaters. Potassium varies from 1 to about 4 mg/l as K normally. Variation with the seasons is not marked. Concentrations above these normal maxima occur from time to time and are frequently signs of contamination. Sodium in particular is a useful pollution indicator because it is often found in effluents in appreciable concentrations. Ion exchange reactions in soils may occur causing some degree of attenuation and therefore elevated sodium levels should always be investigated. One of the most frequent causes of sodium contamination of wells in industrial premises is careless disposal of softener regeneration waste water.

Potassium levels are normally very low as indicted above. This cation occurs in pig slurry in very high concentrations but certain fertilisers are also a source. A useful rule of thumb is the sodium to potassium ratio. For uncontaminated groundwater from limestone aquifers the ratio should be less than 0.1.

Iron and Manganese.

Interpretation of iron and manganese results presents the greatest difficulty as the complete history of the sample needs to be known accurately. A sample taken after the water has been stagnant for a long period is likely to give misleading results. Equally a new borehole which still contains sediment will probably give erroneously high results if the sample is digested in acid prior to analysis (acid digestion of samples for metal analyses is a very common laboratory practice; the result will include not just the "soluble" metal but also anything brought into solution as a result of the digestion).

It is difficult to state normal range values for these two metals because of the problems referred to above. However, experience indicates that in boreholes in daily use, iron <u>if present</u>, is usually in the range from 0.05 to 1.5 mg/l Fe. Manganese, <u>if present</u>, is usually in the range 0.03 to about 1 mg/l Mn. Normally the concentration of iron will exceed that of the manganese where both occur simultaneously but it is not often the case that manganese occurs alone.

The areas of the country where iron and manganese occur naturally are well known to hydrogeologists. It is important to remember that these two metals are present in soils in quite high concentations (they are after all essential "nutrients"). They are normally held in their insoluble oxidised chemical forms but under certain conditions they can be solubilised and become mobile. The sudden appearance of these two metals in a previously free groundwater should be regarded with concern particularly if there is also a detectable odour of hydrogen sulphide.

Copper, lead and zinc.

Many laboratories routinely report copper, lead and zinc. The main reason for this is that these metals are present in plumbing systems. Some waters are naturally corrosive and if corrosion is taking place there will be elevated concentrations of these metals particularly in first flush samples. Lead is of course no longer used in modern plumbing practice but many older houses still contain lead pipes. Zinc is used in brass fittings and of course as the metal used in galvanising steel tanks and pipes. It is unusual for these metals to be found in groundwater.

Alkalinity.

In Ireland, the alkalinity is usually due entirely to bicarbonate ion (HCO_3^-). Nearly all laboratories report it as total alkalinity, expressed conventionally as $CaCO_3$. The term "total" reflects the fact that more than bicarbonate can contribute to the alkalainity but if the pH of the sample is less than pH 8.3 and greater than pH 5, it is reasonably safe to assume that bicarbonate is the only significant species present. The range found in Irish groundwaters is from about 50 to 350 mg/l as $CaCO_3$.

Alkalinity is often "associated" with calcium and magnesium and so as the latter increase so also does the alkalinity. In the case of limestone aquifers, the alkalinity is numerically usually at least 50 to 65% of the total hardness. With few exceptions the alkalinity will be less than the hardness. Cases where it exceeds the hardness should be investigated. The alkalinity should not show a wide variation from season to season and any unexpected variation from the average would be indicative of a problem. As in the case of calcium and magnesium, alkalinity is not a particularly useful contamination indicator.

Chloride

The range found in Ireland is from 10 to 30 mg/l and the average is about 20 mg/l as Cl. Normally one would not expect any significant variation in chloride on repeated analysis of the same source and an increase of more than 5 mg/l should be investigated. Chloride of more than 30 mg/l should also be investigated as this would be regarded as reasonable grounds for suspecting some contamination. In coastal areas, as for sodium, elevated chloride would be due to sea spray or to possible salt water intrusion.

Chloride is a very cheap and reliable indicator of contamination from landfills as leachates usually contain significant concentrations and little or no attenuation takes place. Many effluents also contain an appreciable chloride content and contamination of groundwater by these is often conveniently detected by chloride measurement.

Sulphate.

Normally sulphates are in the range 8 to 20 mg/l as SO_4 and there is usually no seasonal variation. Elevated concentrations occur in the Cavan-Monaghan area and only in one or two other spots in the country. Sulphate is not a good contamination indicator.

Nitrate.

This parameter has become very topical over the past twenty years particularly in the UK where extensive research work on its removal is under way. Assessment of the significance of nitrate in groundwater is somewhat controversial. Some claim that the nitrate level in water which has not been affected in any way by human activity should not exceed 5 mg/l as NO_3. The range found at EOLAS is 0.5 to 120 mg/l as NO_3. The average value is 15 mg/l. The number of samples that have exceeded 50 mg/l is actually small being of the order of 9% of the total examined. It is probable safe to say that a nitrate exceeding 5 mg/l as NO_3 is the result of spreading agricultural waste and artificial fertiliser on lands. Effluent from septic tank/percolation disposal systems is becoming a more frequent cause for elevated local nitrate levels.

Somewhat paradoxically, if nitrate is absent from a water where previous experience has shown that it is normally present, this may in fact be a sign of contamination. In such cases the nitrate may well have been oxidised by bacteria because of anoxic soil and sub-soil conditions caused in turn by effluent or slurry spreading.

Nitrite

The nitrite determination is both simple and inexpensive yet it is a good indicator of trace levels of contamination. The detection limit is about 5 to 10 μg/l (ppb) as NO_2 and so small concentrations can be detected. In the vast majority of cases, nitrite is a short lived intermediate in the oxidation of ammonia and certain nitrogen containing organic compounds in domestic and often effluents arising from the food industry. If it is detected it is a good indicator that all is not well and further investigation is warranted.

Ammonia.

In some respects ammonia is similar to nitrite as an indicator of contamination but there are cases where it occurs naturally in groundwater. Strictly, in these cases it occurs as ammonium (NH_4^+) ion, which if the pH and temperature are favourable, can be a source of ammonia. Many analytical methods actually give what is termed "total ammonia"; this is the sum of the ammonia and ammonium contributions. As a general rule if ammonia is found above 0.05 mg/l as NH_4, the possibility of contamination should be investigated.

Phosphate

On only three occasions in the past ten years has phosphate been detected by EOLAS in groundwater. Even in waters that were grossly contaminated there was no detectable phosphate (< 0.01 mg/l PO_4). As a contamination indicator parameter it is of little utility. Experience shows that phosphate is tightly bound in the top and immediate subsoils and only under exceptional conditions does it migrate downwards. The same does not of course hold true for nitrate which is why it is in contrast to phosphate, is such a useful indicator parameter.

Total Organic Carbon (TOC).

TOC is a relatively modern parameter and is slowly gaining in popularity as a quality indicator. It is more widely used in the United States than Europe but it is listed in the EC Drinking Water Directive although not in the Irish regulations.

It is an instrument based technique and determines virtually all forms of carbon with the result reported as mg/l C. It is similar to BOD and COD in this respect i.e., individual carbon containing compounds are not identified.

EOLAS experience shows that the TOC of uncontaminated groundwater is generally less than 1 mg/l as C. In fact the majority of results are less than 0.5 mg/l C. Elevated levels (1 - 2 mg/l C) have been found where the thickness of the overburden is not great or where rock outcrops occur in reasonable proximity to wells. In places where there is potential rapid infiltration (e.g., East Galway) of surface water elevated TOC's also occur — results of 2 to 4 mg/l C have been obtained.

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SECTION ONE

IRON AND MANGANESE REMOVAL

Iron is present in most igneous rocks (formed by solidified molten rock), shales, clays and, to a lesser extent, as a minor impurity in limestone.

Levels as low as 1 ppm can cause staining and slightly higher concentrations produce metallic tastes and seriously affect the appearance of food and beverages.

Dissolved iron in water is usually in the ferrous state and this is readily oxidised to the ferric state by dissolved oxygen and precipitated as the reddish brown ferric hydroxide. Surface waters therefore normally contain only small amounts of dissolved iron.

Ground waters however pass through soil, pick up carbon dioxide, humic and tannic acids as well as organics and minerals. Normally the deeper the water penetrates, more minerals are dissolved and the organics and most of the dissolved oxygen are lost.

The water will now reduce insoluble ferric iron to soluble ferrous iron.

Since most ground waters contain free carbon dioxide, ferrous bicarbonate is normally formed.

When deciding how to remove iron from water, it is necessary to establish what form the iron takes.

Elemental iron:- is insoluble and in the presence of air and moisture, is oxidised to ferric oxide (rust).

Ferrous iron:- is normally in solution.

Ferric iron:- is normally present as ferric hydroxide and is a very insoluble material.

Organic iron:- takes many different forms which are generally either soluble or sub-micron in size.

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Examples are:-

(a) Bacterial iron

Bacteria can convert ferrous to ferric iron and this then becomes part of the sticky sheath around the cell.

(b) Colloidal iron

Colloids are very small insoluble particles; less than 1 micron; which carry a high surface charge and as a result will not settle, form emulsions and are very difficult to filter.

(c) Soluble Organic iron

Organics such as humic acid are excellent chelating agents and these organics hold the iron in solution.

All the above organic iron types can be treated with strong oxidising agents such as chlorine, $KMnO_4$, hydrogen peroxide, then followed by filtration.

Non-bacterial organic iron can be removed using anion resins, although they may require intermittent acid cleaning.
Other forms of iron can be removed by procedures such as aeration, chlorination and filtration but where low levels are required column filtration, using iron removal media, should be considered.

In many countries, iron content is limited to 0.2 ppm and manganese to 0.05 ppm and preferably 0.1 and less than 0.01.

SECTION TWO

COLUMN FILTRATION

Column filtration uses a pressure vessel with an internal distribution system, sequencing valve, manifold and control panel.

A typical sequence is service - backwash - rinse - return to service. Air scour is not normally carried out on iron/manganese filters but may be required intermittently.

The level of dissolved iron and manganese in the feed water determines the service flow rate to be used and the backwash frequency.

Backwash rates are normally 2 - 4 times greater than service flow rates and this should be taken into consideration when sizing filters or installing supply pipework.

It is advisable to backwash filters on filtered water and this is undertaken by either using a backwash storage tank or by using two filters to backwash one.

Where this cannot be accommodated, an extended fast rinse will have to be used to remove as much of the precipitated iron from the lower distribution system as possible, before putting the plant back on line.

The temperature of the water is an important factor in determining the backwash rate. Warmer waters which are less viscous need higher flow rates to expand the bed 35 - 50%.

The level of oxygen dissolved in the water supplies is an important factor in the removal of iron and manganese. The amount of dissolved oxygen is dependant on several factors, the two main ones being temperature and pressure.

Temperature	Atmospheric Pressure
0°C	
0	14.7
10	11.3
15	10.0
20	9.0
60	3.6

The paper will describe three types of filter media used in the removal of dissolved iron and manganese from water supplies using column filtration.

SECTION THREE

BIRM

Birm is used to remove dissolved iron and manganese compounds from water and is an insoluble catalytic agent. It enhances the reaction between the dissolved oxygen and the iron and manganese compounds by absorbing them along with any dissolved oxygen on its surface. This close contact allows the oxygen to oxidise the iron and retains it long enough to allow the insoluble ferric hydroxide to form and the resultant precipitate to grow.

The catalyst is a manganese dioxide coating bonded to a light silicon dioxide core. This lightweight media allows low backwash rates to be used to ensure proper fluidisation and cleaning of the bed.

Birm is not consumed in the process and the only losses during backwashing are the fines produced by attrition.

APPLICATIONS:-

1) The dissolved oxygen in the influent water must be 15% of the total iron content. Higher levels of oxygen produce better results and "snifter" valves may be used.

2) For manganese or combined iron and manganese the oxygen should be 15% or more of the total.

3) The pH for iron removal should be greater than 6.8 and for manganese or a combination of the two should be greater than 7.5 and preferably between pH 8 and 9.

   The pH can be raised using either soda ash or caustic soda.

LIMITATIONS:-

1) Low pH - as the ferrous bicarbonate is oxidised carbon dioxide is formed, which disassociates into carbonic acid lowering the pH even more.

2) High pH - when treating for manganese with pH values between 8 - 9, any iron present could form as colloidal iron which will not be removed.

Continued.../

Limitations (cont.)

3) Waters containing high levels of sulphate and chlorides attack the manganese dioxide coating and the bicarbonate (alkalinity) should be twice the combined sulphate plus chloride.

In saline waters if ferrous sulphate and chloride are oxidised the resultant sulphuric and hydrochloric acids block further reaction.

4) No hydrogen sulphide should be present. Birm will remove H_2S but the precipitated sulphur fouls the bed. The presence of H_2S would also suggest low levels of oxygen as the demand for oxygen by H_2S is six time greater than that of iron.

5) Organics to be less than 5 ppm.

Organics could foul the bed and organic iron will not be removed.

6) No oil - it coats the media.

7) Polyphosphates - these sequestering agents should be dosed after the filter.

8) Chlorine - should be 0.5 ppm or less.

Occasional shock sanitization is allowed but continuous chlorine dosing is not recommended.

9) Temperature - not to exceed 38°C - the ability to hold oxygen decreases with temperature.

10) Iron/manganese influent - 3 ppm norm. up to maximum 10 ppm.

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(Cont.).../

PHYSICAL CHARACTERISTICS

Form - Black granules

Density - 750 - 800 kg/m^3

Size - 0.5 mm

OPERATING CONDITIONS

Flow rates - Note m/hr = m^3/hr/m^2

Service

iron up to 3 ppm - 6 m/hr

iron up to 0.5 ppm - 12 m/hr

Backwash - 25 m/hr

"Capacity" = 1 kg/m^3

NB. The "capacity" is not used up but the precipitate can be forced through the filter if the figure is exceeded.

Maximum Pressure Drop

2 - 4 psi, (from clean bed)

Bed Depth - 100 cm

Bed expansion - 35 - 50% of bed depth.

MANGANESE DIOXIDE

This is another example of an insoluble catalytic agent. It is a naturally occurring mineral, crushed, free from additives and from contamination.

It is dark brown in colour and is very resistant to attrition.

It is produced from an ore high in catalytic activity and is accurately screened to 0.5 - 1.0 mm. The particle size is essential in ensuring that even though silica sand and manganese dioxide have different densities, when mixed together the manganese dioxide will distribute itself evenly throughout the sand bed.

To produce a catalytic filter using manganese dioxide it is usual to have a ratio of 20% manganese dioxide and 80% silica sand.

The manganese dioxide is added on top of the sand and the unit is then backwashed until the media is thoroughly mixed. If the particle size were too large, the high density manganese dioxide would fall to the bottom of the bed, reducing contact time, with the resultant reduction in iron and manganese removal efficiency.

The manganese dioxide in contact with the sand produces an effect whereby the sand assists in the catalytic oxidation and since the process is catalytic the efficiency is proportional to the catalytic surface area.

As with other catalytic media, it is important to ensure adequate oxygen is present in the water, that the pH is between 6.5 and 7.5 and that there is at least 100 mg/l alkalinity in the water.

If ammonia is present in the water, this must be destroyed by chlorination. Sufficient chlorine should be added to produce a free chlorine residual throughout the filter bed activating the manganese dioxide.

In effect the chlorine oxidises the manganese dioxide to permanganate with the chlorine being reduced to chloride. The permanganate produced rapidly oxidises manganese in solution to form manganese dioxide at the surface and the permanganate is reduced back to manganese dioxide.

Continued.../

MANGANESE DIOXIDE (cont.)

Both precipitated manganese dioxide and ferric hydroxide are absorbed onto the surface of the media without impairing activity and thus the media is able to act as a filter of suspended solids as well as being able to adsorb other toxic metals.

A contact time of five to six minutes is required at a flow rate of 10m/hr, and approximately 0.5 mg/l chlorine is consumed by the filter media.

PHYSICAL CHARACTERISTICS

Shape	granular
Colour	dark brown
Size	0.5 - 1.0 mm
Bulk Density	2.0

OPERATING CONDITIONS

Flow rate	10m/hr
Backwash	40% bed expansion

SECTION FIVE

MANGANESE GREENSAND

This manganese zeolite is an oxidising and filtering media manufactured from naturally occurring granular like sand which is green in colour when dry.

It has catalytic properties which enhances the reaction between the dissolved oxygen and iron/manganese. When used in conjunction with an oxidising agent such as potassium permanganate or chlorine, it will reduce iron and manganese to extremely low levels.

In this application, rates of reaction are substantially increased and the oxidation process moves rapidly to completion.

The nodular form and particle size ensures excellent filtration properties once the iron or manganese has been precipitated.

The greensand is very durable and is not used up in the process.

APPLICATION:-

Oxidisation/reduction - In the same way that ion exchange resin has the capacity to exchange ions, manganese greensand can exchange electrons. Therefore, as long as a supply of electrons is available, iron and manganese can be oxidised. The electrons can be replaced by adding potassium permanganate, either continuously or by regenerating the filter media.

Catalysis - The catalytic effect ensures that the maximum use is made of the oxidising agent; potassium permanganate, chlorine or dissolved oxygen.

Filtration - Good filtration characteristics are obtained due to the high contact area established by the size and shape of the product.

Two basic techniques are used, the choice depending primarily on the level and relative amounts of iron and manganese in the water.

When iron is the primary objective, the continuous technique is used.

When manganese is the problem, the regeneration technique can be used.

Mixed techniques can be used for large units when both iron and manganese have to be reduced to very low levels.

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DOSING LEVELS (cont.)

Regeneration - Recommended on waters where only manganese or manganese with small amounts of iron are to be removed.

Dosage = 3g $KMnO_4$/litre media

Pre-chlorination is recommended particularly if iron is present. If chlorine is used then less permanganate will be required.

TYPICAL PHYSICAL, CHEMICAL AND OPERATING CHARACTERISTICS

Appearance : black, nodular granules shipped in a dry form

Oxidation Capacity : 0.7g Mn/1 or 1.4g Fe/1

Particle Size Range (dry) : 0.25 - 1.0mm

Effective Size : 0.30 - 0.35mm

Shipping Weight : approx. 1350 g/l

RECOMMENDED OPERATING CONDITIONS

pH Range : 6.5 - 8.5

Maximum Operating Temp. : 40°C

Max. Differential Pressure across the bed : 0.85 kg/cm^2

Minimum Bed depth : 700 mm

SUGGESTED OPERATING CONDITIONS

CONTINUOUS:-

Capacity -	350 - 450- g/m^2 of bed area, based upon the ionic load. Since the manganese and iron require different amounts of treatment chemicals, this load is conveniently calculated as the potassium permanganate demand. This calculation is made by the chosen process from the alternatives give above. The recommended bed depth is 0.7m unless the bed diameter becomes unacceptably large. Where larger bed depths are necessary, the pressure drop across the bed will increase pro rata.
Backwash Rate -	The backwash should produce around 40% bed expansion. Backwashing is required when the pressure loss reaches 0.85 kg/cm^2 for a standard 0.7m bed.
Flow Rate -	If concentrations of iron and manganese are high, then lower flow rates are required for the equivalent run lengths. The usual flows for the continuous process are 5 to 12 m^3/hour m^2. This is adjusted, according to the permanganate demand (dependent on the total iron or manganese content) as given below:

Ionic load expressed as Permanganate Demand ppm	**Maximum Flow Rate** m^3/hour/m^2
0.5	12
1.0	10
2.0	8
3.0	6
5.0	5

Continued.../

CONTINUOUS (cont.)

In order to achieve the best results, a layer of anthracite, depth of 0.35mm to 0.4m is recommended, on top of the bed of greensand.

The continuous process sequence is backwash, rinse and return to service, all requiring about 20 minutes. When backwashing with treated water, this rinse may be unnecessary.

EXAMPLE

Calculation of the size of filter to treat 20m^3/hr of a water containing 1.5 ppm iron and 0.5 ppm manganese. Determination of run length and $KMnO_4$ demand.

$KMnO_4$ demand : 1.5 (Fe) x 1 + 0.5 (Mc) x 2 = 2.5 ppm

Specific flow required (from above table) : 7m^3/hr/m^2

Filter cross section : 20 (m^3/hr) /7 (m^3/hr/m^2) = 2.857m^2

Filter diameter : (2.857/) x 2 - 1.907m

Nearest available - vessel diameter : 2.0m

Design cross section : 3.14m^2

Design spec. flow rate : 20 (m^3/hr) / 3.14 (m^2) = 6.37m^3/hr/m^2

Approx. run length : 400 (g/m^2) / 2.5 (ppm) = 160 m^3/m^2

Hence : 160 / 6.37 = 25 hr

Qty of greensand required : 3.14 x 0.7 = 2.2 m^3

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REGENERATION PROCESS:-

Capacity - 0.7 g of Mn per litre, or 1.4 g of Fe per litre. Pre-Chlorination is recommended, particularly if there is iron present. If chlorine is used, less potassium permanganate is required.

Backwash - The backwash should be at a rate to give a 40% bed expansion.

Regeneration

Potassium permanganate dosage - 3 g per litre

Potassium permanganate solution strength - 0.3 - 0.5%

Potassium permanganate regeneration rate - 2
litres/hour/litre

Potassium permanganate regeneration time - 30 mins minimum

Rinse rate - 8 litres/hour/litre

Rinse volume - 5 litres/litre, or until all traces of potassium permanganate have been removed.

Pressure drop - Maximum allowable pressure drop 0.85 bar, for the standard bed depth, pro rata for deeper beds. If the pressure differential occurs before the capacity for Mn has been exhausted, the greensand can be backwashed without a regeneration.

Flow Rate - 5 - 12 m^3 per hour/m^2, according to the ionic load based upon the total iron and/or manganese content, calculated as follows:

Ionic load as Fe = 1 x ppm Fe + 2 x ppm Mn.

Continued.../

Flow Rate (cont.)

This notional iron load is used to calculate the maximum flow rate in the table below.

Ionic load as (Fe) (Iron and Manganese)	**Maximum Flow Rate**
ppm	m^3/hour m^2
0.5	12
2.0	10
3.0	8
5.0	7
10.0	6

The regeneration process sequence is backwash, regeneration with a dilute solution of potassium permanganate, rinse and return to service, all requiring about one hour.

Treated water is recommended for backwashing unless the iron and manganese in the raw water are very low. To maintain the bed in a clean condition, occasional air water washes are recommended.

EXAMPLE

Calculation of the size of filter required to treat $5m^3$/hr of a water containing 1.2 ppm iron and 1.0 ppm manganese. Determination of run length;

Ionic load (as Fe) : 1.2 (Fe) x 1 + 1.0 (Mn) x 2 = 3.2 ppm

Specific flow rate (for load of 3.2 ppm) : $8m^3/hr/m^2$

Filter cross section : 5 (m^3/hr) /8 ($m^3/hr/m^2$) = $0.625m^2$

Filter diameter : (0.625(m^2)/) x 2 = 0.892m

Nearest design diameter : 1.00m

Design cross section : $0.78m^2$

Qty of greensand required : $0.546m^3$

Oxidation capacity : 546 1 x 1.4 g/l = 764g Fe

Run length : 764/3.2 = $239m^3$ (48h)