Irish Group

International Association of Hydrogeologists

Enquiries to : Frank Clinton
Seminar Secretary
Sligo County Council
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Portlaoise Seminar - April 1993

Dear Colleague

The Irish Group of the International Association of Hydrogeologists are delighted to announce plans for their 1993 Seminar at the Killeshin Hotel in Portlaoise on April 21st and 22nd.

As you may be aware, this is one of the most important annual seminars for those working in the area of Water Resource exploitation, management and pollution control. The content of this seminar will be of particular interest to Engineers, Planners and Scientists involved in the supply of water.

The main themes of this years seminar will be :

- Water Data Management - Information Technology.
  Speakers will deal with matters such as Hydrometric Networks, Basin Management, GIS, Modelling, Regional and local ground water monitoring and the interactions between rivers and groundwater.

<u>and</u>

- The Dolomite Aquifer of Counties Kilkenny and Tipperary.

  This will include talks on Geology, Drilling, Longterm pump testing, Hydrochemistry and Modelling.

Further information will be forwarded to you over the coming weeks, when the final arrangements have been made. I hope that it will be possible for you to attend the seminar this year, and I look forward to seeing you in Portlaoise.

Yours sincerely

F Clinton

Frank Clinton

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Groundwater Report - Summary Sheet

Report Number: GW 93/6 Author(s): F. Clinton (Ed)

Report Title: Basin Management & Information Technology an Aid to Regional Planning. Date Completed: May 1993

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Copy of the report in:

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Area Concerned:

National: Yes [/] No [ ]

Regional: Yes [ ] No [ ] Which region: ____

River Catchment(s): ____

County(s): ____

Local area: ____

6" Sheet No.: ____ 25,000 Sheet(s): ____

Principal Groundwater Topics Covered: Monitoring, Pumping Tests, Limestone Development(N.Cork), Dolomite Aquifer and Legislation

Geological Succession Covered: ____

Objectives in Writing Report: ____

Other remarks: This report is the proceedings of the IAH Meeting in Portlaoise.

I A H SEMINAR APRIL 20 & 21 1993

BASIN MANAGEMENT & INFORMATION TECHNOLOGY AN AID TO REGIONAL PLANNING

DAY 1 TIME TABLE

TIME	TOPIC	SPEAKER	ORGANISATION
10:00-10:45	Registration & Coffee		
10:45-11:00	Presidents Address & Welcome	K. Cullen	IAH Irish Group
11-00-12:00	Regional Groundwater Monitoring	J. Boswinkel	Institute of Applied Geoscience, Holland
12:00-12:30	Groundwater Monitoring in N. Ireland	P. Bennett	H.E.S. Ltd.
12:30-12:45	**DISCUSSION**		
12:45-14:00	LUNCH& EXHIBITIONS		
14:00-14:50	Catchment Monitoring & Managment	G.A. Burrow	National Rivers Authority
14:50-15:30	Ardnacrusha & Management of the		
	Shannon Catchment	A. Shaw	Electricity Supply Board
15:30-15:45	**DISCUSSION**		
15:45-16:15	COFFEE& EXHIBITIONS		
16:15-16:40	Data Acquisition	S. McCarthy	Hyperion Energy Systems
16:40:17:15	Data Processing & Manipulation	T. Joyce	Office of Public Works
17:15:17:40	Computer Modelling	Dr. R. Kachroo	University of Dar Es Slaam
17:40:18:00	**DISCUSSIONS**		
18:00:19:00	Wine & Cheese Reception		

DAY 2 TIME TABLE

TIME	TOPIC	SPEAKER	ORGANISATION
9:00-9:30	Hydrogeology of Dolomite Aquifers		
	of South East Ireland.	E. Daly	Geological Survey of Ireland
9:30-9:50	Large Scale Pumping Tests	K. O'Dwyer	K.T. Cullen & Co. Ltd.
9:50-10:10	Groundwater Development in N. Cork	Pat Walsh	Cork County Council
10:10-10:25	**DISCUSSION**		
10:25-11:00	COFFEE & EXHIBITIONS		
11:00-11:30	Groundwater Legislation	Owen Boyle	Dept. of Environment
11:30-12:00	Grey & Black List Substances	T. O'Flaherty	EOLAS
12:00-12:30	Geographical Information Systems	D. Moore	NGIS Ltd.
12:30-12:45	**DISCUSSION AND CLOSE**	K. Cullen	IAH Irish Group

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ALAN CHAPPLE	KIRK McCLURE MORTON
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SHANE BENNET	KT CULLEN & CO LTD
S McCARTHY	HYPERION ENERGY SYSTEMS
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DAVID RYAN	KILKENNY COUNTY COUNCIL
B GREGORY	KIRK McCLURE MORTON

BASIN MANAGEMENT & INFORMATION TECHNOLOGY
IAH seminar April 20 & 21 1993 Dublin

Watermanagement, Monitoring & Information systems

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Contents

1 TNO Institute of Applied Geoscience

TNO is the Netherlands Organization for Applied Scientific Research. TNO was established in 1932 by a special act of parliament. Its primary tasks are to support trade and industry, the authorities and other groups of the community in technological innovation, and to assist clients and sponsors in solving problems.
TNO does this by rendering services and transferring knowledge and know-how, either to invididual companies or to research associations. Know-how is obtained from TNO's own research, through collaboration with others, or by exchanging or purchasing knowledge. The organization has seven divisions. These TNO divisions together comprise some 25 research units (Institutes) each with 30-600 employees, which have their own budget responsibility.

The TNO Institute of Applied Geoscience is part of the Division TNO Environmental and Energy Research. It was established in 1967 to contribute, via sciences research, to the proper management and use of subsurface natural resources. The Institute has currently a staff of 130 and in 1992 its turnover was 25 million Dutch guilders (some 12 million ECU).
In the Netherlands the renewable resources, particularly groundwater, are managed by the government and the provinces. This is based on their importance to integral water management, water supplies and maintaining the natural subsurface environment.
The exploration and exploitation of groundwater is carried out mostly by or on behalf of the industry.
The government also manages the non-renewable natural resources: oil, natural gas, geothermal energy and other mineral resources. This is related to their economic significance and the safeguarding of the Netherlands' energy supply. The exploration and exploitation of energy sources and minerals are undertaken by or for industry.
For these reasons government as well as industry commission TNO research activities. This research covers groundwater as well as geo-energy.

The main fields activities of the TNO Institute of Applied Geoscience comprise:

* Groundwater research, development and investigations
* Groundwater monitoring networks and information systems
* Oil and gas seismic research and development
* Oil and gas reservoir research, development and investigations
* Geoscientific institution building in developing countries.

Groundwateractivities

The policy of the Dutch Government is focussed on sustainable management and use of the environment and subsurface natural resources.
Groundwater is playing an important and complex role as a scarce and thus valuable resource, as a vurnable environmental compartment, and as a transportmedium for all kinds of substances.
To sustain this policy, there is an increasing need for unambigious reliable information of a high quality regarding the groundwater.

TNO Institute of Applied Geoscience is the central institute in the Netherlands for groundwater data acquisition and monitoring, data analysis and system assessment, modelling and information management.
The main objective of the TNO Institue of Applied Geoscience with respect to groundwater in the Netherlands is to supply comprehensive information and state of the art tools for the efficient management, use and protection of groundwater resources.
The main activities comprise:

* Data acquisition
* Monitoring networks
* Analysis of geohydrological data
* Analysis of groundwater systems
* Modelling flow and transport
* Groundwater information systems

2 Watermanagement

Introduction

From the earliest times onwards, water has been an essential element to mankind, in the first place to satisfy direct biological needs for this element. Initially, man will have drunk water where he happened to find it and will have eaten food that had absorbed water in a quite natural way, without any human interference. Once nomadic man settled down, around 6000 years ago, his restricted radius of action forced him to face both the struggle against water (floods and inundations) and the struggle for water (for domestic use and for irrigation). In response, he developed technological skills: impressive hydraulic engineering systems existed already in ancient times and testify that hydraulic engineering belongs to man's earliest technological achievements. Examples are the antique irrigation schemes in the Egyptian Nile Valley and Mesopotamia, khanats in Iran and neighbouring countries, the Marib dam in S.W. Arabia and the Roman aquaducts.

Thus, water has become gradually an economic commodity and one of the main 'fuels' for development. Water now plays a role in many facets of everyday's life : as a source of water for domestic use and irrigation; as production and cooling water in industry; as an essential element for navigation, fishery and recreation; as a source of energy; as an agent to dispose of sewage and other waste; sometimes as a threat to man's life or activities; and finally as an important environmental factor. This has led to the existence of numerous water-related activities in almost any region in the world.

Separate activities regarding or affecting water will not automatically add up to an optimal use and conservation of a region's water resources. On the contrary, providing guidance (by a policy) and implementing corrective measures may greatly enhance the overall net benefits from the resource and often are necessary to avoid major problems. Such activities are the domain of water resources management.
Water resources management thus means **intervention** in matters concerning water. Such matters may be the planning, design or operation of hydraulic works, but they may also be factors that are related indirectly to water (e.g. land use, as a factor affecting groundwater quality).
Water resources management presupposes that an authority exists powerful enough to impose decisions upon individuals or -- at least -- to influence people's behaviour. So it focusses on **protecting the collective interests** in water resources and guaranteeing that recognized individual or sectorial water requirements continue to be satisfied.

Groundwatermanagement issues

Groundwater resources development and other groundwater-related engineering activities are becoming quickly more intensive and pollution risks are increasing year after year, in many countries of the world. As a result, the interferences are becoming more and more pronounced which brings about a growing need for **integrated management** of the resources. Progress in water resources sciences and improved computational facilities are paving the road to this integrated approach. The main groundwater management issues comprise:

* <u>Allocation problems</u>

Considering groundwater as a resource to be abstracted and used, we may face different types of allocation problems : allocation among users, spatial allocation and temporal allocation.

* <u>Conjunctive management of groundwater and surface water</u>

Groundwater and surface water tend to be strongly interrelated, in the sense that groundwater may feed surface water bodies, and vice versa. Variations of flow, storage or quality of water in one of the subsystems may directly affect the state of the other one. These variations may have a natural cause (e.g. weather conditions), but they can also be provoked by water resources management activities. Artificial recharge, base flow suppletion and surface water dams are typical examples of the latter category. Furthermore, the availability of both surface water and groundwater in an area opens the possibility of conjunctive use of groundwater and surface water.

* Groundwater salinity control

Many aquifers contain both fresh groundwater and saline or brackish groundwater. The fresh zones usually are recharged by rain or by streams.
The purpose of groundwater salinity control is to **prevent or minimize salination of the fresh groundwater resources**, to conserve the resource for future use. Salinization of a fresh part of an aquifer is partially irreversible (as a consequence of dispersion processes), thus is difficult to cure. Hence, protective measures are required, and such measures should be designed on the basis of simulation. Examples of salinization are: Salt water upconing, Saline water intrusion and Soil salinity.

* Groundwater pollution control

One of the most obvious options to protect a well field against pollution is to locate it at a suitable site (well field protection).
Once in existence, well fields in many countries are protected against pollution by establishing so-called **groundwater protection areas**. Inside these areas there is usually a distinction between several zones: closer to the well field the control becomes more and more strict. The dimensions of the different concentric protection zones are based commonly on estimates of the time it would take for a contaminant to arrive at the wells.
Protection of the entire aquifer against pollution has become a major concern during recent years, after more and more cases of severe contamination have been discovered in many different countries. As far as the diffuse sources of pollution are concerned, it becomes clear that control of land use and agricultural practices may contribute highly to the conservation of groundwater quality. Strict regulations on the disposal of industrial and hazardous domestic waste may greatly reduce point-source pollution.
Mapping of the vulnerability of aquifers to pollution, and study of the transport of solutes in groundwater (preferably in a 3D approach) are valuable methods to guide how to minimize the effects of the remaining pollution sources.

* Groundwater level control

The level that should be considered as the optimum **groundwater level** varies according to soil type, land use and climatic conditions. In agriculture, there is considerable empirical knowledge on the relation between yields of groundwater-fed crops and the depth to groundwater. Ecologists have similar information on the relation between depth to groundwater and the survival or modification of ecosystems. In the urban sector, in general, there are certain requirements on minimum depths to groundwater to be maintained. Thus, different sectors will come up with different requirements regarding the target groundwater levels. This leads to spatial variation in drainage depth criteria.

* Control of land subsidence

Significant land subsidence may occur as a consequence of groundwater abstraction or groundwater level control. This may be expected in particular when important drops of hydraulic head are produced in zones where water-saturated peat, clay or silty layers occur at relatively shallow depths (within some tens of metres from land surface).
Limiting land subsidence is in such cases an important constraint to water resources development.

Elements of water resources management

Water resources management consists of a number of steps, carried out in succession:

- assessment of the water resources system
- assessment of water demands/requirements
- identification of water resources management problems, objectives and constraints
- development and analysis of alternative strategies and instruments for implementation
- decision-making
- preparing for implementation (legislation, organization, planning)
- implementation
- monitoring (water availability, quality, demands, supply)

Different instruments are available to implement groundwater resources management strategies. All these instruments must comply with laws and customs in vigor, hence : what is possible and effective in one area might be completely excluded in other environments. It is important to define the implementation instruments already during the phase of modelling and decision-making; only in that case it will become clear whether proposed strategies might be feasible.
An important tool for groundwater management implementation and control is the monitoring activity. Monitoring activities are necessary throughout the process of the assessment of water resources, the planning for groundwater resources management and the implementation and control of the chosen policy.

Information flow

The data-collection activities will result in an enormous amount of data, which need carefully management; special attention should be paid to quality control. The dataflow is understood to mean those stages which data go through, beginning after measuring the required parameters via the processing, the presentation and the storage of data, till the information is used in decision making.

3 Monitoring Networks

Design and implementation

All differnt activities regarding or affecting water will not automatically add up to an optimal use and conservation of a region's water resource. On the contrary, providing guidance and implementing corrective measures may greatly enhance the overall net benefits from the resource and often are necessary to avoid problems. One of the important elements of this necessary water resources management is the monitoring of the groundwater.

The monitoring network can be described as:
a system of spatial distributed observation points, observed at different time intervals, so that the conclusions can be drawn from the measurements concerning the behaviour of the measured phenomena within the measured space and time.

It will be obvious that the number and location of the observation points in the monitoring network and the number and kind of measurements which have to be carried out in the time, are determined principally by the watermanager's original objective. The formulation of the objective of a monitoring network is the first and maybe the most crucial step for the design and implementation of a groundwater monitoring network; an incomplete formulation of the objective can lead to a deadlock in the future: i.e. the monitoring network will not be capable of providing the required information.

Once the objective has been defined, the design of the network can begin. On the basis of available local knowledge and physical knowledge, the expert can make an initial estimate of the parameters which are to be measured, the order of magnitude of the observation frequency and the density of the monitoring network, as wel as the measuring techniques to be employed; the design also implies the technical design of the measuring stations.

After the design has been completed, the implementation of the network can start. Important in this matter is the representativity of the observation point.
For the measuring activities an adequate organisation is required, including aspects as: supervision of the observers, periodic inspections of the measuring stations (network maintenance) and of the nmeasuring equipment, and a protocol for data-acquisition and -collection.

Once the monitoring network (together with its database) is operating properly, periodic evaluation is necessary to check whether the monitoring network is actally operating completely, and whether it is fulfilling the expectations which has been set for at the time, or new objectives have to be incorporated in the network. Furthermore the evaluation can provide an impetus for the optimalization of the monitoring network. As a result of carrying out measurtements, the knowledge of the measure location will in fact have increased. As a consequence of this, it is possible that in the future the measuring effort could be reduced.

Groundwater monitoring networks in The Netherlands

As a result of the implementation of a new Groundwater Act in the early eigthies, tasks and responsibilities for groundwatermanagement are shifted from the central government to the provincial governments. This has also resulted in a differentiation of the groundwaterlevel networks in the Netherlands:

* Provincial groundwaterlevel monitoring networks
  The twelve provincial groundwaterlevel monitoring networks result together in the national network (approximately 4000 observation points).
  These networks are ment for groundwatermanagement characterising the groundwaterregime on regional scale. Moreover these networks have a reference functions for other (local) networks for actual and future groundwatermanagement and research.
  The networks are under the responsibility of the Provinces; in some cases the management of the networks is delegated to TNO. 11 out of the 12 provincial groundwaterlevel monitoring networks are designed by TNO.

* Geohydrological monitoring network of TNO
  Originally TNO had the task to manage, maintain and operate most observation wells in the Netherlands (foundation of Groundwaterlevel Archives TNO in 1948).
  Changing watermanagement responsibilities and research needs has led of an adaption of the task of TNO. It is now redesigning its network focussing on geohydrological research as well as a task management of the observation wells of general interest, complementary to the provincial monitoring network; the actual size is approximately 10,000 observation points.

* Phreatic monitoring networks
  There is a growing interest for information of the phreatic water behaviour. Nature conservation organisations and waterboards have increasing networks for respectively ecological purposes and for surface water level control.

* Local groundwaterlevel monitoring networks
  Local groundwaterlevel monitoring networks are implemented for control of groundwaterlevels because of specific interests and needs. Examples are monitoring networks around watersupply abstraction wellfields, groundwater abstracting industries and in urban areas.

About 75% of the observation wells is measured twice a month. This is done by over 4,000 persons. About half of them are in service with governemental, public or private organisations. The other observers are individuals which are taking the measurements voluntary.
All measurements of about 17,000 observation wells in the Netherlands (about 500,000 per year) are sent to the central database of the TNO Institute of Applied Geoscience.

4 Geohydrological Information Management systems

Introduction

Since the introduction of the computer in the natural sciences the work environment of the scientist is in a period of transition: from manual and mechanical data collection to electronic recording, from paper files to computerized databases, from manual to computer-assisted elaboration and interpretation of field data, from hand-made to computer-made maps, from manual combination of independently calculated parameter values to integration and calibration of parameter values by means of numerical simulation techniques, from "guestimating" future developments to testing and optimizing different scenarios and forecasting their impact on the water system, etc. Also the relationship between the scientist or technician and the computer changed dramatically.

The use of computers in geohydrology started in the nineteensixties and early nineteenseventies when geohydrologists replaced the resistor/capacitor analog models by numerical simulation methods that were run on the large computers of that time. With the advent of the desk top computer and easy programming languages in the late nineteenseventies and in the nineteeneighties users started to make their own software that took care of tedious plotting or repetitious calculations. From then on, we have seen the software applied in the geo-scientific environment evolve in a number of steps; from single job-oriented and hardware specific programs consisting of intermingled functions for data input, rudimentary data base management, data processing and information output, towards workstation like systems, showing a trend to separate the data storage system from the processing functionality and the user interface, but focussed on one specific type of information. As a matter of course, such systems can be set up for multiple data types, leading to the introduction of a common interface making it possible to access different databases. This is the current state of affairs, i.e. the technology used in the nineteeneighties.

The next step in the development of geoscientific information systems should be a system in which applications are each connected to a uniform database system and "shelled" by a uniform user interface. This gives the user direct acces, via the application programs, to all the data in the database. Subsequently the results of the intervention with the application programs can be stored, e.g. pumping test data are retrieved from the data base and the transmissivity and storage coefficient of the aquifer are calculated with the application program for pumptest analysis; the calculated aquifer characteristics such as transmissivity and storage coefficient are also stored in the data base and may be retrieved when they are required in e.g. a groundwater model study, etc.

As far as we are aware, there is no geohydrological information system available yet, that fully integrates a data base with the required range of applications to make up a geohydrological workstation. The stepwise introduction of automatization in many organizations has resulted in a patchwork of unrelated software packages for database purposes, for the interpretation of different types of data, for the graphical presentation of interpreted results, for modelling etc. As a result, the software that is currently available in the field of geohydrology is still restricted to an agglomerate of independent programs showing often incompatible output/ input features.
In order to be able to support geohydrological research and managament activities, a geohydrological information system should provide:

* facilities to store and maintain all the geohydrological data collected in an area
* functionality to derive and maintain a geohydrological model of hte area under study
* functionality to use this model in the management phase e.g. to support simulation of the effect of management scenario's; this include GIS functionalities and linkages with numerical simulation models

Developments at TNO

The TNO Institute of Applied Geoscience is responsible for the maintenance and optimalisation of the network but also for the collection, processing and evaluation of the observations and for making the data available to interested public and private parties.
This is how, together with its research activities, the institute acquired considerable expertise in the field of information technology, especially on high volume databases. As a matter of course, the paper files of the groundwater archive were automated in 1970, thereby providing computer support for the activities related to the operation of the observation network and offering new perspectives in the field of dataprocessing and - presentation. Further developments resulted in the birth of the **On-Line Groundwater Archive (OLGA)** providing on-line access to the approximately

12 milion groundwater observation records and 50,000 groundwaterquality analyses, stored in the underlying database. These accomplishments were important steps towards the integration of information processing activities within the institute.

The groundwater managing authorities in the Netherlands have commissioned the Institute to compile and map the occurrence, movement and properties of the groundwater in the Netherlands, so that the groundwater can be used and managed appropriately. For a new generation of groundwatermaps the choice was made to develop an interactive geohydrological information system, REGIS (REgional Geohydrological Information System). REGIS eventually will contain all geohydrologically relevant data and information needed for the proper management and exploitation of groundwaterreserves and for the adequate protection of the soil and the subsoil.

According to TNO - Institute of Applied Geoscience, the time has come to design and implement an integrated information system around a database that supports a wide range of data types and includes application programs for input and output, basic manipulation, elaboration (processing), interpretation, integration (modelling), and presentation of geohydrological data, all addressed through a uniform user-interface. This system will be embodied in the Evaluation of Groundwater resources Information System, abbreviated to EGIS.

A geohydrological information system improves substantially the working environment of the geohydrologists for research and for technical support towards the watermanagement authorities. This covers the trajectory from data-acquisition over conceptual modelling to final decision making.
A geohydrological information system that wants to overcome the problems of the fragmented character of available geohydrological software, should be based on three design principles: integration, flexibility and multi-user operationability. The EGIS system claims to a geohydrological information system in the true sense.

IAH PORTLAOISE SEMINAR, APRIL 1993

GROUNDWATER MONITORING IN NORTHERN IRELAND

by Peter Bennett
H & E S Ltd, 387 Lisburn Road, Belfast.

Development of groundwater for public supply over the last thirty years has included establishing observation wells which have been used to monitor water levels related to particular schemes, over periods ranging from a few months to several years. But as schemes were completed resources were never available to continue monitoring into a long term exercise which would reveal the effects of abstraction.

During the last ten years more concerted efforts have been made to maintain water level monitoring on a continuous basis and some of the results obtained will be present.

Also, systematic monitoring of groundwater quality has been commenced within the last year; this as part of a project in response to EC Nitrate and Groundwater Directives. A water borehole inventory is being built up along with a monitoring network for diffuse pollution, over a two year period. At the same time a Hydrogeological Map (1:250,000 scale) and aquifer vulnerability maps are being compiled. At the end of the project period it is intended that water level and quality monitoring will be continued indefinitely in a representative, but reduced network of boreholes.

The results of the quality monitoring to date suggest that nitrate contamination is not a widespread problem but there are some localised high nitrate levels probably associated with unsatisfactory well construction methods.

IAH SEMINAR APRIL 1993

Hydrological Data and its Application to Catchment Monitoring and Management in NRA Southern Region

Introduction

Responsibility for overall river basin management in England and Wales lies with the National Rivers Authority (NRA), which under the terms of the 1989 Water Act inherited the regulatory and planning functions in Water Resources and Water Quality that were previously carried out by the Water Authorities. The NRA also inherited flood defence regulatory and operational responsibilities. At the same time, water supply and sewerage functions were invested in Water Service Companies.

On its formation, the NRA was organised into ten regions based on the earlier Water Authority areas. These follow catchment boundaries and so provide for integrated management of surface groundwaters from precipitation to estuary. Of course, some water supply systems have historically extended considerable distances outside the source catchments and it has therefore been necessary to take a wider view when planning and managing water resources.

Recently the legislation was updated, mostly by way of consolidation, in the Water Resources Act 1991 which brings together earlier provisions for flood defence, pollution control and fisheries as well as abstraction licensing, drought management and resource conservation. Thus the NRA operates under terms that were largely established in previous decades and has inherited the assets, hydrometric and land drainage, that have been built up over many years for river basin management.

There is however a somewhat different and much clearer environmental protection role in the NRA's activities, compared with the former Water Authorities. The monitoring of abstraction licences is now pursued far more actively than in the past, and some previously exempt abstractions for fish farming and general agriculture have been brought within licensing provisions.

NRA Organisation

At the present time the NRA operates through nine regions and a national headquarters in Bristol, the Yorkshire and Northumbria regions having combined on 1st January 1993. By 1994 this will be reduced to eight regions with the amalgamation of South West and Wessex regions. These changes, and the impending formation of an Environmental Agency in 1995 have implications for the design of new systems for information technology, which must be flexible enough to serve future organisational arrangements that as yet are unknown.

Southern Region

Most of the features described in this paper relate to Southern Region, although reference is made to some developments elsewhere, and of course there are features common to all regions. The Southern Region consists essentially of the Counties of Kent, Sussex, Hampshire and the Isle of Wight, with a population of 4 million and an area of approximately 11,000 sq km. The two largest rivers are the Medway in Kent and the Test in Hampshire but the region is characterised by relatively small rivers draining the central clay weald and flowing directly into the Channel. The dominant topographical features are the chalk uplands of the North and South Downs and Northern Hampshire, which provide the bulk of the region's water supply. Low lying coastal land in parts of the Isle of Wight, Western Hampshire, West Sussex, Thames Estuary and Dungeness is vulnerable to tidal flooding and is protected by extensive sea defences, but inland flooding risk is limited to a few specific locations. Figure 1 shows some of the main features and towns of the area.

Information needs arise from three main types of functions:

Monitoring
Operations
Planning

In many cases the type of information required is the same but the timing varies, and with the inclosed monitoring role now exercised there has been an increased need for telemetry of data that has traditionally been gathered manually.

Hydrometric Networks

In the field of hydrometry extensive networks of raingauges, flow gauging stations and observation boreholes provide continuous or frequent observations of the natural hydrological cycle, from which resource availability for planning purposes has been and continues to be assessed.

Rainfall

The raingauge network is the oldest established with a number of sites providing records from the 19th century. The network depends on volunteer observers who read gauges daily at 9am and enter readings on postcards that are then posted at the end of the month to the office maintaining the record. In most parts of England and Wales this is the Meterological Office but in the Southern Region it is the NRA, where data is entered onto a regional mainframe system that carries out quality control checks before accepting values into storage. This system, and the other hydrometric systems, is accessed through terminals in seven Area Offices and at Regional Headquarters in Worthing. A data tape is prepared automatically each month and sent to the Met Office for entry into the national system run at Bracknell. There are some 440 daily read gauges, distributed as shown in figure 2, which provide a comprehensive and cheap network.

Information on rainfall (or the lack of it) has been in much demand over the past three years and will continue to be examined as an indicator of severity of the prolonged drought that has affected South and East England since late 1988. A deficiency of over 600mm, or nearly a year's rainfall, had accumulated in Kent by the early summer of 1992 (see figure 3), causing exceptionally low groundwater levels and requiring a high level of activity by the NRA and Water Companies to restrain public water supply demand and bring into operation new and 'mothballed' sources.

The manual data handling cycle, typified by the daily raingauge network, has been augmented since the mid 1980's by tipping bucket recording gauges linked to solid state data loggers and in some cases to telemetry outstations. Information from these is applied at the other end of the scale, to flood warning, flood operations and drainage design. There are now nearly 100 of these recording gauges in the region, the majority being Didcot 0.2mm tip size linked to PDL 10 data loggers or DTS TG 1150 outstations. Data from the loggers is collected monthly by take-away memories that are downloaded on to a stand alone PC rainfall events data system maintained in each area office. Unlike the daily rainfall system, this does not have built in quality controls nor is it networked between area offices. It does however have the good graphical displays and presentations associated with more recent PC software.

A further source of rainfall information is provided by weather radar. For South East England the coverage is limited, coming from the Chenies site north west of London. Much of the Region is beyond the range of reliable quantative information but the radar picture is valuable as back up to telemetering raingauges and gives a good indication of the extent and movement of precipitation, particularly frontal systems. A display is maintained in the regional 24 hour control room and will shortly be available in real time at each area office over the regional communications network. Much of the flooding that occurs is either directly tidal or aggravated by the tidal retention of fluvial flows, but the town of Tonbridge in Kent has suffered flooding over many years from the River Medway and is now protected by an upstream detention reservoir operated by the NRA. This is backed up by a rainfall-runoff model that predicts inflows and thus aids the setting of the discharge gates in order to capture the hydrograph peak. The model is driven by telemetered rainfall and river level information.

Groundwater

As might be expected in an area where three quarters of public water supplies are drawn from underground sources, there is an extensive observation borehole network throughout the major aquifers. Water level readings are routinely taken at over 1000 sites (see figure 4), typically at monthly intervals, by NRA hydrometric staff. The majority of these are by manual dipping but a significant number have autographic chart recorders such as the ott R16 and a start has been made in bringing key groundwater sites on to the regional telemetry system. This is partly as a result of the drought and the need to monitor falling levels and also any recovery, and also an expression of the more general NRA monitoring role. In future a number of sites in particularly sensitive areas or close to surface waters known to be affected by abstraction will be included in the telemetry system, as well as some of the more remote locations. Manually gathered water level readings are entered on to a regional mainframe groundwater archive accessible in the area offices, from which contour maps and hydrographs are obtained.

Despite the number of sites already monitored, gaps remain, and model studies of particular aquifer blocks continue to bring out the need for infilling of observation wells. New boreholes have recently been put down in the Arundel area of West Sussex and are currently being drilled in the Darent catchment in north west Kent. In both areas the need to manage the aquifer in a more environmentally sensitive way has required modelling of alternative abstraction conditions under a range of recharge assumptions, with the objective of reducing abstractions at times and locations having the worst effect on surface flows. The NRA is now beginning to seek arrangements with Water Companies to secure improvements in the most adversely affected catchments, and has recently reached agreement in principle with Thames Water over a sequence of measures to improve the Darent. Because these abstractions are all licensed, the question of compensation arises and will be a major issue for the immediate future.

More generally, the NRA has adopted a policy of licensing no further abstractions from the chalk and lower greensand in Kent, and has made clear its view that very little additional groundwater is available for the time being from the chalk in Northern Hampshire and Sussex. In order to support this policy, at public inquiries if necessary, a good data base of groundwater level, rainfall and abstraction information is essential and groundwater models will increasingly be required to develop and apply a defensible recharge criterion for licensing purposes. The former use of average annual recharge has led to the type of problems referred to above and no longer fits the NRA's environmental management role, and specifically would not be compatible with the setting of minimum acceptable flows in surface streams dependant on groundwater baseflow.

<u>Rivers</u>

The surface flow monitoring network, which covers some 60 primary sites and a larger number of secondary gauges uses data loggers to record water levels, with autographic chart as the back up medium. Levels are normally recorded every 15 minutes on to solid state memories which are collected once a month and downloaded using PC software in area offices. The PC produced raw data is transferred to a regional mainframe data processing system which has validation procedures and converts level readings into flows, using gauging station reference data which is stored as station history details. A primary archive of mean daily flows, with data from the early 1960's, is maintained for on-line access throughout the region. For those sites dependant on charts, PC based digitising software is used to generate digital level data which is also input to the mainframe flow system and handled thereafter in the same way. All basic raw level data is also retained on computer archive so that retrospective changes in stage discharge relationships can be incorporated if necessary and instantaneous level values are available, typically for flood design purposes.

Most flow gauging stations are either a recognised standard structure, such as single or compound crump or flat vee weir, or a rated natural river section. In the 1960's, following the 1963 Water Resources Act, there was an active hydrometric network construction programme, and the Crump profile weir was favoured, but more recently the flat vee design has been adopted almost exclusively, as it causes less afflux and is less obtrusive that the compound weir with its divide walls.

A smaller number of electromagnetic and ultrasonic river gauges have also been installed, and current and future installations will increasingly look to these two methods to measure flows where low heads or tidal or backwater effects preclude hydraulic structures. Whilst not entirely without difficulties, the ultrasonic method does provide a viable method of gauging wide, slow rivers without prohibitive construction costs, and the NRA is currently sponsoring further development of the technology as part of the national R & D programme. Although the surface water gauging network is reasonably dense, with an average catchment area of about 180 sq km per primary gauge, there are significant gaps where difficult conditions have in the past inhibited flow measurement. Paradoxically, these are some of the most important sites from the point of view of catchment management and monitoring. Major abstractions are often at tidal limits and of course this is the point at which total freshwater flow should be measured. A number of major abstractions, both in Southern Region and nationally, have not been adequately monitored in the past, leaving downstream reaches vulnerable to poor quality conditions. A survey, again part of the NRA national R & D programme, identified 44 such sites where flow measurement was required but not implemented because of low velocities or tidal influences.

A temporary ultrasonic gauge, having 4 horizontal paths, was installed in 1992 in the tidal River Stour in Kent as part of an investigation programme designed to set acceptable abstraction conditions for a proposed new pumped storage reservoir with an intake 20km inland from the sea. Figure 5 shows the water level and flow recorded at this site over a period of 15 days. The values have yet to be verified by check current metering but the results are promising, and a second such temporary installation is planned for the River Ouse in Sussex. The figure does also show that the phrase 'river flow' requires careful interpretation at such tidally affected sites.

In narrower rivers, at less than about 20 metres width, the electromagnetic coil method has been found economic and is successfully established at 4 sites in Hampshire, and a new gauge is under construction on the River Stour, upstream of the tidal range. There, it will replace a rectangular weir structure and improve the river for migratory trout movement. The Thames, Severn Trent and Wessex regions also have electromagnetic gauges.

Most key river gauges have now been incorporated in the regional telemetry system, permitting continuous monitoring of sensitive reaches. This is particularly relevant where river augmentation schemes are in operation, on River Medway in kent, River Ouse in Sussex and River Itchen in Hampshire. In general, such augmentation schemes are operated by the Water Companies in support of abstractions for public water supply, and it is part of the NRA's role to monitor compliance with the relevamt licence conditions. The telemetered data is used for real time 'alert' reporting but is not incorporated in the primary hydrometric data archives already described. A task for the future is to devise adequate quality safeguards for data gathered by telemetry before it is stored for long term use.

Domestic Water Supply

In addition to the traditional and familiar hydrometric networks, the Southern Region operates, in conjunction and with the support of the Water Companies, a network of domestic water consumption monitoring areas covering a population of 40,000. This network was conceived in the early 1980's to measure unmetered domestic water consumption, the largest component of public water supplies in the region. As only 3% of homes were metered, information on consumption was almost non-existent, with consequent uncertainty in planning for the future. The monitoring areas vary in size from 50 to 2000 population, and so far as possible consist of homogenous socio economic housing types. Individual homes are not metered and householders pay by rateable value, so that the measurement process in no way impacts on consumption. District meters at the inlet to the monitored areas are connected to solid state data loggers, which record flow every 15 minutes. Logger memories are downloaded using PC software at monthly intervals, and the raw data is sent to NRA regional headquarters by the Water Companies for consolidation. Regular reports are provided from the system, which is entirely PC based, to the participating Companies.

An example of the detailed record from an area is shown in figure 6. Results from all the areas are analysed annually by housing type to give estimates of per capita consumption in each type. The relation between house type and consumption has been found to be consistent, with the pattern shown in figure 7 recurring each year, albeit with year on year overall increases or decreases.

This consumption data is vital in quantifying the various components of water put into supply networks, and has greatly assisted in determining losses from supply systems. Clearly, an understanding of present water use is also a prerequisite to forecasting the future, but until recently such projections had little basis in fact.

A notable feature of domestic (and total) consumption in south east England in the last 4 years has been its decline. Until 1988 per capita consumption was increasing, reaching an average 147 litres/head/day in 1988, since when it has fallen to 139 litres/head/day. Such a reversal makes forecasting a particularly interesting task at present.

Water Resource Planning

Responsibility for the overall planning of water resources lies with the NRA, under the provisions of the Water Resources Act 1991, and a national resources development strategy is currently being produced. This has drawn on resource yield and water demand data to establish the present base, and will look forward to a 2021 planning horizon. It will consider to what extent inter regional water transfers and major new reservoirs are required, and indicate those options favoured by the NRA.

At the same time, individual regions are examining their local situations in more detail. Southern Region published its own draft development strategy late in 1992, and has invited the local community, in the form of County and District Councils, environmental interest groups, MP's, Friends of The Earth etc, as well as the Water Companies, to comment. There has been widespread support for the policy of demand management advocated in the strategy document. If implemented, there is no doubt that expensive new schemes will be deferred, the need for long distance imports into the region avoided and further deterioration in spring flows and empheral streams halted. There will also be sufficient resources to ameliorate some of the worst affected catchments.

Catchment Mangagement Plans

On a wider front, the NRA is producing catchment management plans that bring together major issues of river flow and level, quality, conservation, navigation, fisheries and recreation, and present problems and possible solutions for consultation with a range of bodies and individuals. These plans draw heavily on hydrometric and water quality data in presenting their reviews, and the consultants working on this task for the NRA, W S Atkins, have used Autocad extensively. One advantage of this has been the consistency of map representation between different catchments.

An example of some of the management options identified in the River Test catchment in Hampshire is shown in Figure 8.

Summary

Whilst the NRA has inherited and built on extensive hydrometric networks and data processing systems, its particular environmental monitoring role has given a different emphasis to this activity and uncovered some important deficiencies in measuring lowland rivers, abstractors' flows, localised aquifer levels and groundwater quality generally. Data processing systems for the future will need to be compatible with GIS design and at the same time be flexible to survive future organisational changes as a result of the impending formation of the Environment Agency.

G A Burrow

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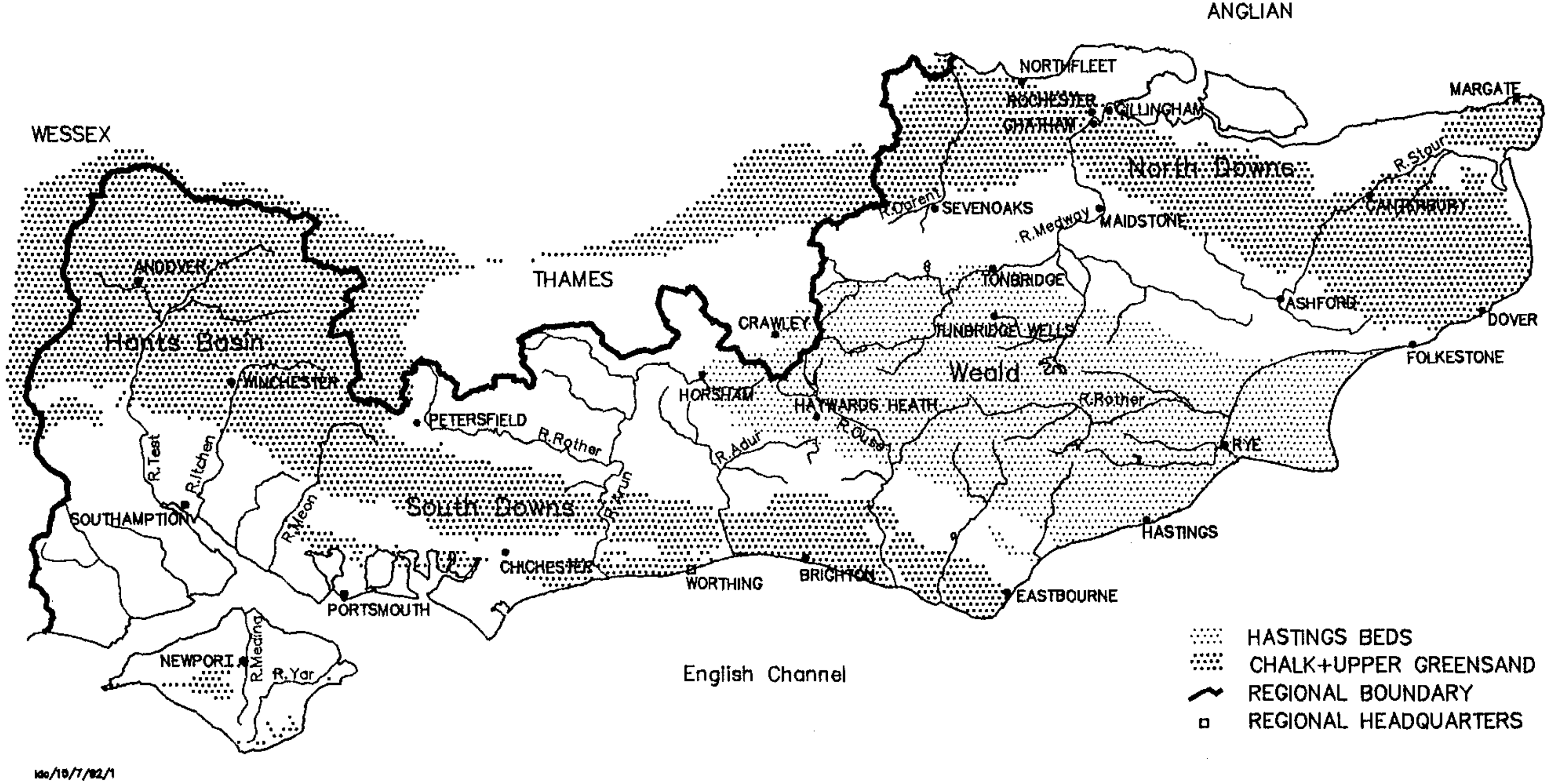
NRA SOUTHERN REGION

Fig 1

PRINCIPAL AQUIFERS, RIVERS AND TOWNS



Daily Raingauges

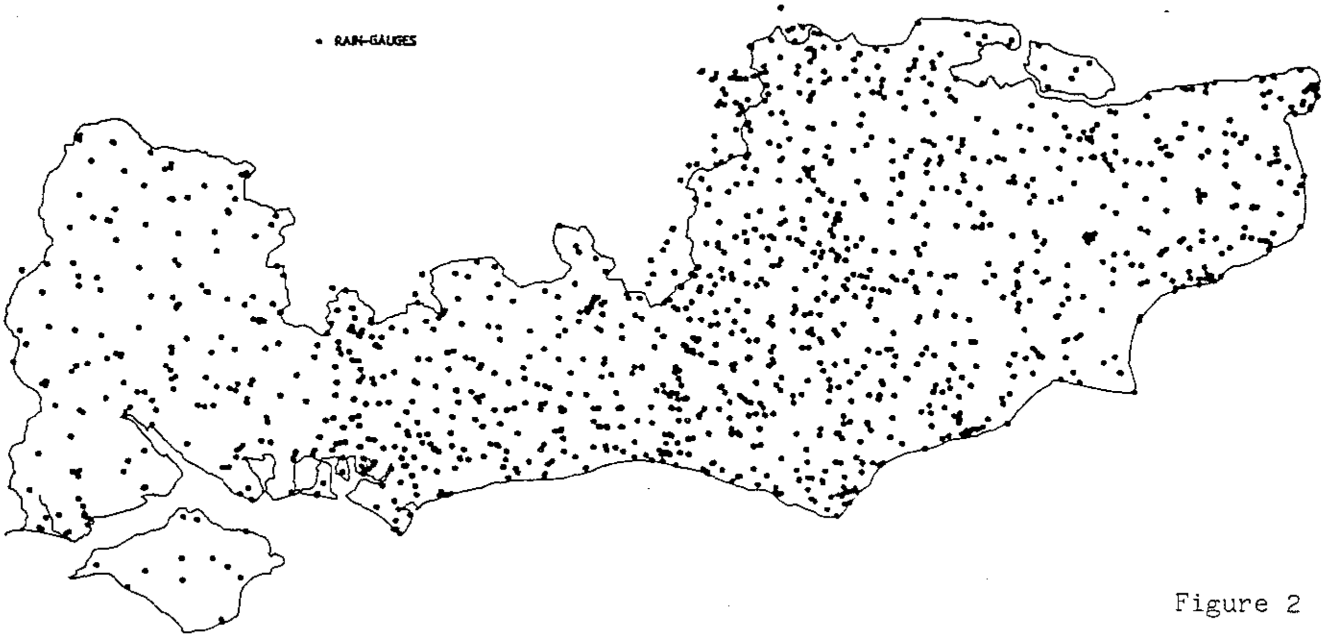


Figure 2

CUMULATIVE ACTUAL AND AVERAGE RAINFALL
KENT AREA

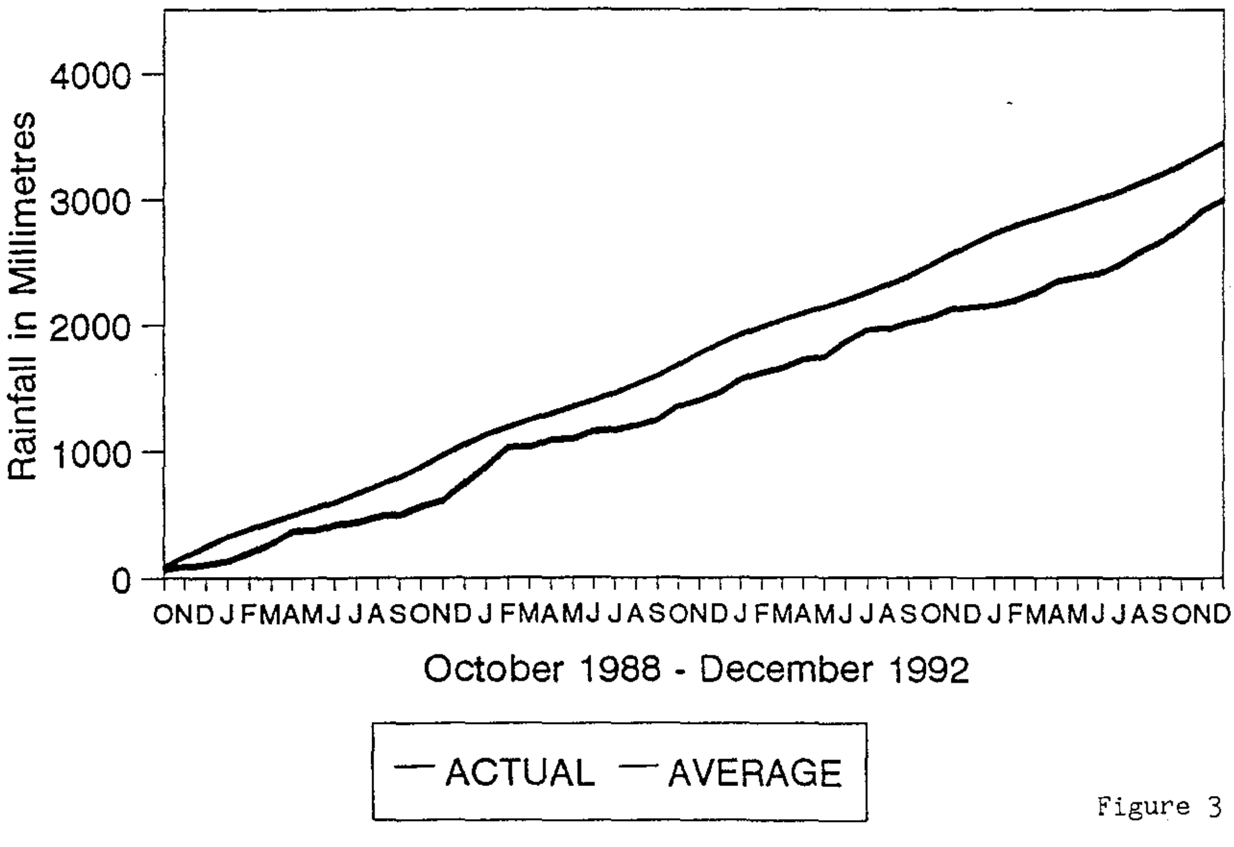


Figure 3

Observation Boreholes

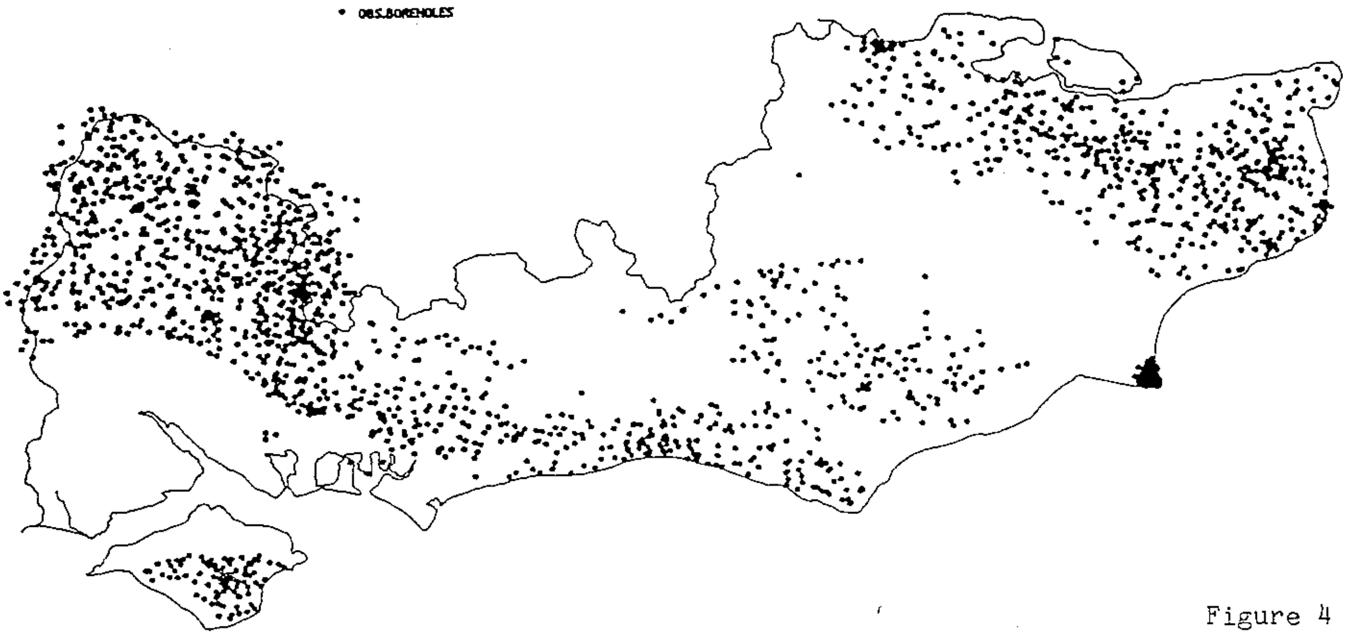


Figure 4

Ultrasonic Flow Gauge in Tidal Estuary

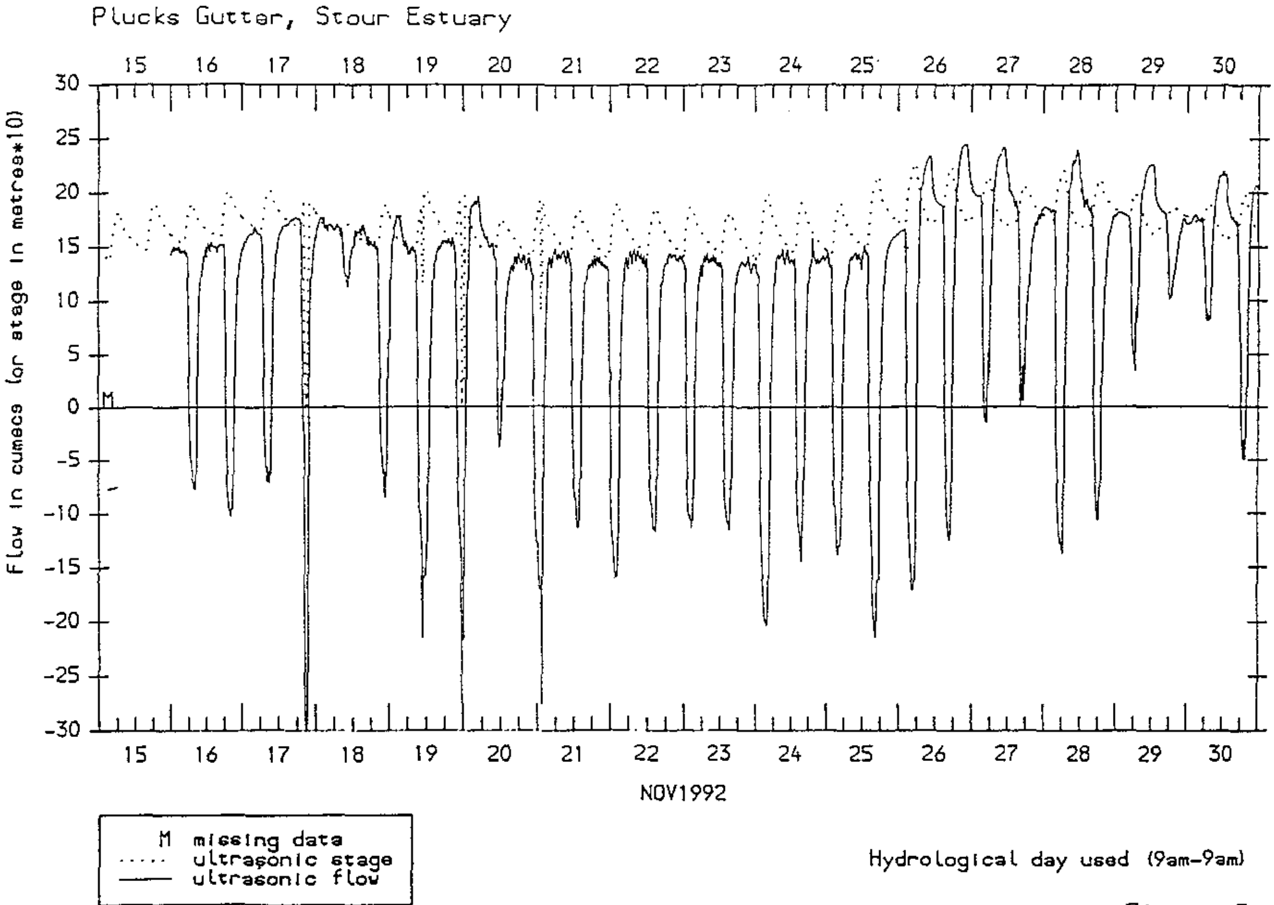


Figure 5

Domestic Water Supply Monitoring

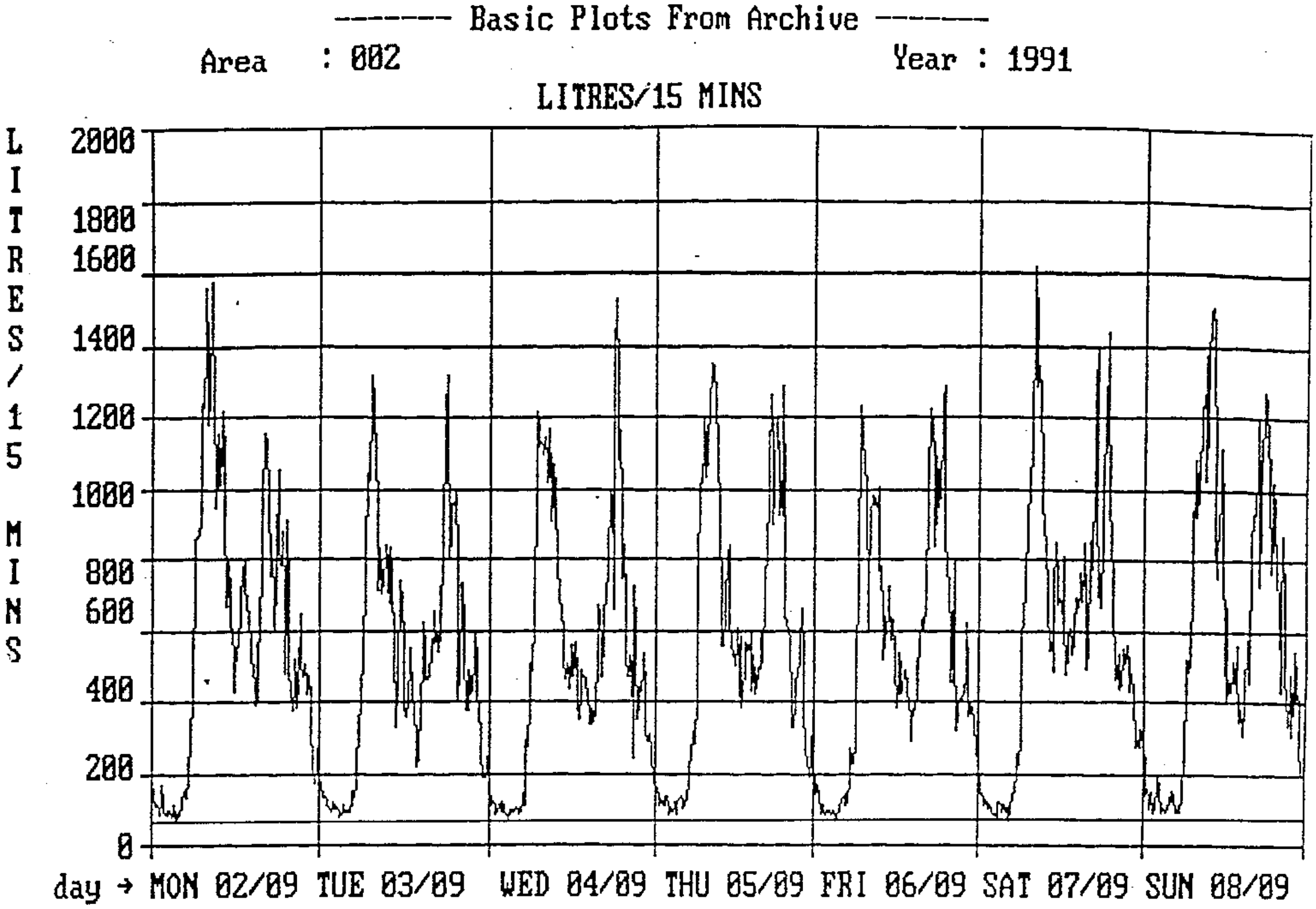


Figure 6

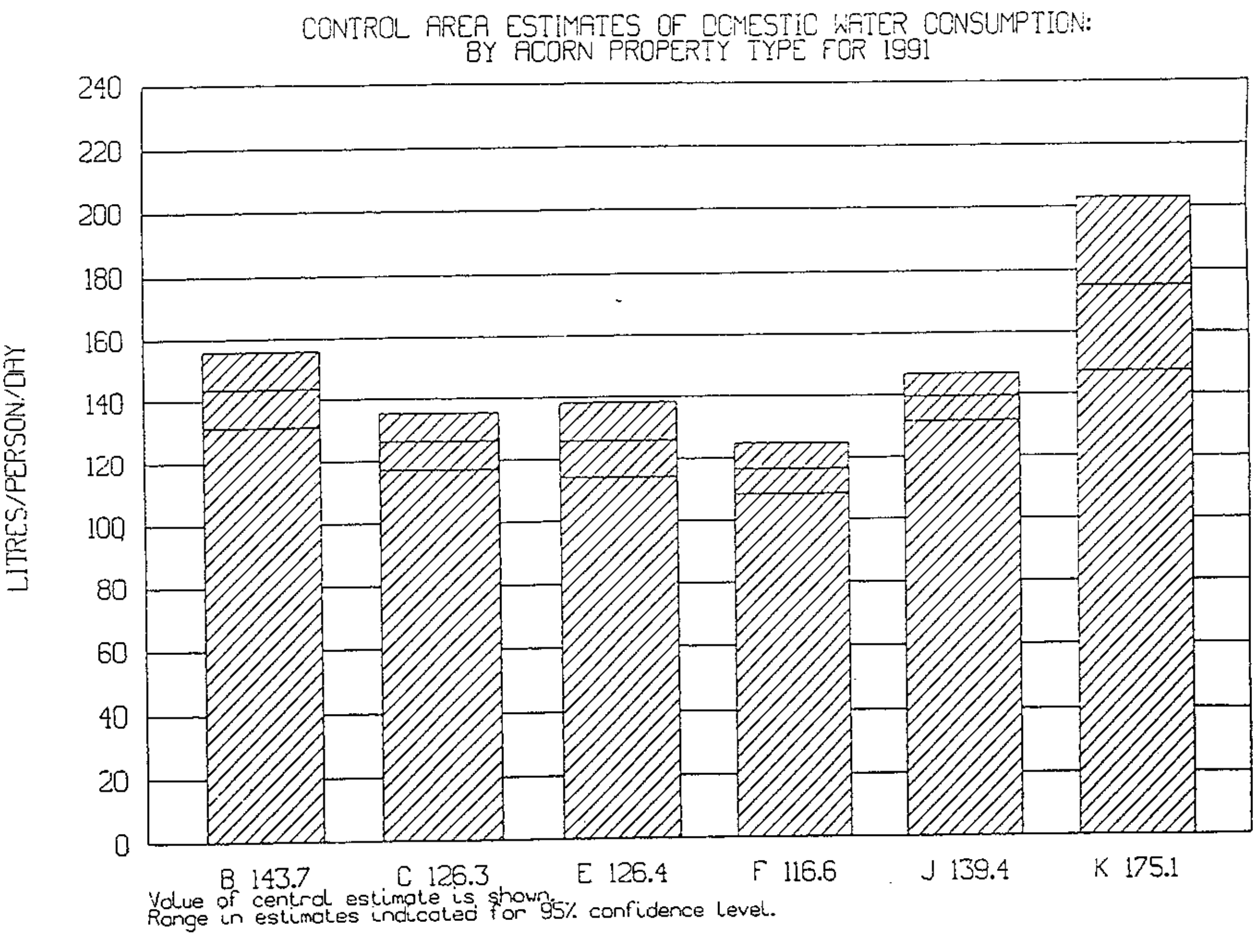


Figure 7

Example of Catchment Management Plan Options (R. Test)

Issue Ref. No. 1	Poorer conditions in the river due to shallow depths, turbid waters and lack of weed		
Management Option	Responsible Bodies	Pros.	Cons.
Reduce cross-sectional area of river, through for example:			
° Infilling over-deep or dredged sections.	Landowners; Test and Itchen Fishing Association with NRA advice	Improves flow velocities.	
° Closing off the flow of some of the carrier channels.	Ditto	Ditto	Loss of reaches for fishing.
° Reducing the width of the river channel by infilling from the banks; particularly in the old disused mill heads.	Ditto		Potential loss of bankside habitat.
Return to traditional river management practice of autumn weed cutting in areas where this is not consistently carried out at present.	Landowners; Test and Itchen Fishing Association; NRA	Improved management.	Labour cost.
Provide a surface water augmentation scheme to supplement low flows during periods of natural drought.	NRA	Improves low flow conditions.	Cost; Does not reinstate 'natural' conditions.
Ensure that there are no further consumptive abstractions from the upstream chalk aquifer.	NRA	Increases the securing of surface flows.	Loss of potential for resource development.
Ensure that future water supply is from the bottom of the catchment (both for the Test and Itchen) and fed to any new development in the upper part of the catchment. The effluent from the development can then be treated and returned to the river to help augment flows/groundwater.	NRA; Southern Water Plc	Ditto	Cost; Possible reduction in water quality due to increase in effluent discharge.

Figure 8.

ARDANCRUSHA AND STORAGE MANAGEMENT OF THE RIVER SHANNON

The word "management" in the title should properly be in inverted commas, since the amount of control which can be exercised on the River Shannon is very limited. The catchment is very large, the gradient practically nil, the river channels are generally narrow and shallow and the amount of controllable storage capacity is very small, so that control is rarely possible, and even when it is, has only marginal effect.

In addition a considerable proportion of the catchment is covered by peat bog, which tends to hold back the inflow, extending the time of concentration. That, combined with the flat terrain, produces lengthy floods lasting weeks rather than days, with flat "peaks" and large volumes of water.

All is not totally hopeless however, since a reasonable amount of control is possible over the Summer period, and at either end of the catchment control is rather greater than in the centre.

Nor is it devoid of interest, from a hydrometric point of view. Because of the construction of the Shannon Scheme in the 1920's, many people believe that ESB has great control and are likely to make the most extraordinary demands, most of which are quite impossible to fulfil. In addition, there are many users of the Shannon all of whom have requirements of levels, flows and storage, so that striking a balance between the demands - when control is possible at all - is a difficult problem. Indeed, it is the conflicting demands of the river-users which is the greatest limitation on river control in the summer period.

Ardnacrusha was built to generate power from the waters of Ireland's largest river - it is in fact the largest river in Ireland or Britain. It was never envisaged that there would be any advantageous effects on the Shannon flood problem; there was no pleasure boating on the river in those days and tourist and amenity benefits of the river hardly crossed the minds of the designers. The lakes were to be used to provide storage to augment the flows in Summer and very few other considerations were taken into account. Navigation was the responsibility of the Board of Works. The only control structure which was operated to suit ESB was at Athlone, and any operation of these sliuces which was likely to impinge on navigation would be rare.

In Loughs Allen and Ree, any works carried out under the Shannon Scheme were designed only to improve storage levels, albeit slightly, so the only guideline for operation was that the maximum levels reached prior to the scheme should not be wilfully exceeded.

However, in recent years further restrictions have been voluntarily adopted. These are in the nature of 'gentleman's agreements', depending, in the case of ESB, on weather and system demand being favourable, but as far as possible ESB tries to abide by them. The reasons for their formulation would include, for example:

* the requirement of farmers that lakes should be held wherever possible at a low level to provide drainage and flood storage.
* The requirement in Lough Allen that levels should be between the narrow limits of 47.55 m O.D. and 48.16 m O.D. (156 and 158 ft O.D.) in the summer period to allow the use of Corry strand, and for fishing and tourist reasons, etc.
* The requirement for reasonable water levels in Lough Ree during the summer boating season.

Lough Derg is different. As a result of the weir built at Parteen Villa, water levels in Lough Derg itself are likely to be substantially higher than they were prior to the Scheme during the summer period. Consequently, the land liable to such flooding was either bought or compensation was paid to the land owners. In so far as is possible, winter levels are not allowed to exceed pre-Scheme levels, though nature ultimately has the last word.

It is in the area of Lough Derg that ESB has the most control of the storage. By the Shannon Acts, ESB is entitled to raise or lower the levels in the lake in whatever way is convenient for the operation of Ardnacrusha Power Station in supplying power, within a range of 1.56 metres between the levels of 32.00 m O.D. and 33.56 m O.D. This range covers a storage volume of 188 X 10^6 cubic metres.

In practice, this range is very rarely used. Firstly, it is Lough Derg that provides Ardnacrusha with its head of water, so that it is in the interests of ESB to maintain the level high while still allowing some freeboard for flexibility. Secondly, there are restrictions on rate of draw-down in the headrace banks which are more severe at low levels. And thirdly, both land-owners and boat-hirers prefer higher levels; the former because the ends of fences are revealed at low lake levels allowing animals to stray, and the latter because of the risk of damage to boats at low levels. Generally, the operating range of Lough Derg is between 32.80 m O.D. and 33.56 m O.D.

Although Lough Derg is a large lake in the geography of Ireland, the volume of storage available in the normal operating range of Ardnacrusha Generating Station is equivalent to less than 3 days running with zero inflow. In addition, draw-down of this magnitude in such a short time would be likely to cause considerable adverse community reaction and could also cause damage to the banks. Consequently, in the dry summer period, Ardnacrusha is of little value to the power system except as an assistance for peaking.

At the other extreme, flood inflows soon raise the level of the lake to unacceptable levels. The discharge of Ardnacrusha at normal full load is 360 m3/sec and at overload is 390 m3/sec. Every 14 m3/sec above this value will raise the level of Lough Derg by 1 cm in a day. Obviously, ESB tries to operate the station during the winter months at a level that will provide some storage in the lake for floods, but except in the most benign of floods this storage buffer is quickly filled. When the level of Lough Derg at Killaloe reaches 33.56 m O.D. and the inflow exceeds the capacity of the station, the excess water is spilled through the gates at Parteen Weir.

A year without some flood spill at Parteen Weir is rare. The average inflow to the catchment in the wettest three months of the year is 320 m3/sec so that winter storms almost inevitably lead to spillage. The worst flood recorded on the Shannon occured in February 1990 (in magnitude it was very similar to the flood of 1954/55). The peak flow at Killaloe in this flood was estimated at about 800 m3/sec; the peak outflow was 750 m3/sec, 400 m3/sec discharged through the sets at Ardnacrusha and 350 m3/sec released at Parteen Weir. For comparison, the 1,000 year flood in the river is estimated at 1350 m3/sec.

Except in the area of the catchment closest to Ardnacrusha, the management of the river is based on gauge readings taken once a day at 9 a.m. In general, this is quite adequate in a catchment as slow and lethargic as the Shannon. Closer to the power station, at Parteen Weir and Ardnacrusha itself, levels are continuously recorded in the Control Room at Ardnacrusha. In addition, the levels of the three lakes can be interogated by telephone at any time.

By 10 a.m. each day, a complete picture of the levels, storage, inflows and discharges along the main stem of the Shannon from Lough Allen to Ardnacrusha is available.

To assist in the forecasting of inflows to the Shannon at Killaloe, and the consequent load conditions, use is made of the five-day meteogram for the South Shannon region. This is received from the Meteorological Office each morning before 7 a.m. and gives a forecast of the expected weather conditions for the next five days. Although the rainfall accuracy is variable it is better than nothing, and is useful so long as its limitatations are understood.

The unit hydrograph for the Lough Derg catchment is applied to the actual (past) and the forecast rainfalls and the estimated local inflows calculated. These inflows added to the calculated flow into lough Derg give an estimate of the water available for generation at Ardnacrusha. The flow of the Shannon entering Lough Derg, being the product of a flat, boggy catchment, reacts slowly to rainfall. However, the response of the local catchment is much faster, the peak of the unit hydrograph occuring within 24 hours.

Of the many fallacious beliefs abroad in relation to the control of the River Shannon, probably the most widespread is the misconception that flood waters are artificially held back in the middle Shannon, particularly between Meelick/Banagher and Athlone. The 'holding back' is real enough unfortunately, but it is done by Mother Nature, not by ESB - nor even by the OPW! The size of the natural channel and the lack of gradient are the villains! Long before any flood levels are exceeded, all sliuces upstream of the area have been closed and those downstream opened.

Thus, it has been shown that the amount of control or management of the waters of the Shannon is minimal. In general, apart from the area of Lough Derg, the ESB's role tends to be more a matter of ensuring;
- where control is possible, that the ill-effects and benefits are reasonably evenly divided and,
- where there is no control, that the enquiring public is provided with any information available to ESB as to the causes of their problems.

Data Monitoring For Environmental Engineering Systems

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SUMMARY:

Computerised Data Monitoring Systems are used to automatically collect data from electronic sensors and store it in a format suitable for analysis. They produce accurate, consistent and reliable data provided the sensors are properly calibrated. This paper gives an overview of data monitoring systems, their capabilities, their limitations and their costs. In particular, it will provide a check list of criteria which should be considered when selecting a system. It will examine for example, the choice of sensors, data collection hardware, computer interfaces and computer software. The paper will also examine the suitability of data collection systems for environmental monitoring in remote application i.e. using modems, radio links, portable PC's, hand held data collection systems etc.

CASE STUDIES:

The following systems were installed by Hyperion and these will be used to illustrate how data monitoring can be used for environmental engineering applications.

a) **Biophore System**
for Bord Na Mona Peat Research Centre

b) **Pollution Monitoring System**
for Glashaboy Waterworks, Co. Cork.

c) **Effluent Monitoring System**
for Bord Na Mona, Peat Research Centre.

1. INTRODUCTION

Computers have been used in industry in two main areas: -on the shop floor and in the company management. On the shop floor they have been used in the automation of process and the most popular device is theProgrammable Logic Controller (PLC). On the management side their most popular use has been in financial accounting and administration.

Computerised data collection systems are systems which collect data on the shop floor and transmit it (in the form of reports) to management. The technology to implement this has been available for a long time but it was limited because of cost. In the past number of years three major developments have made data collection economical:

1. *The availability of low cost powerful computer systems.*
2. *The development of hardware/software specifically for this market.*
3. *The availability of personnel with skills in all of the areas of data collection.*

2. COMPUTERISED DATA COLLECTION SYSTEMS

The layout of a computerised data collection system is shown in figure 1. It typically consists of:

- ***Sensors***

  These are electronic devices which convert physical values into electrical signals. e.g. Temperature, Ph, Flow rate, etc.

  A comprehensive list of typical sensors is outlined in table 1.

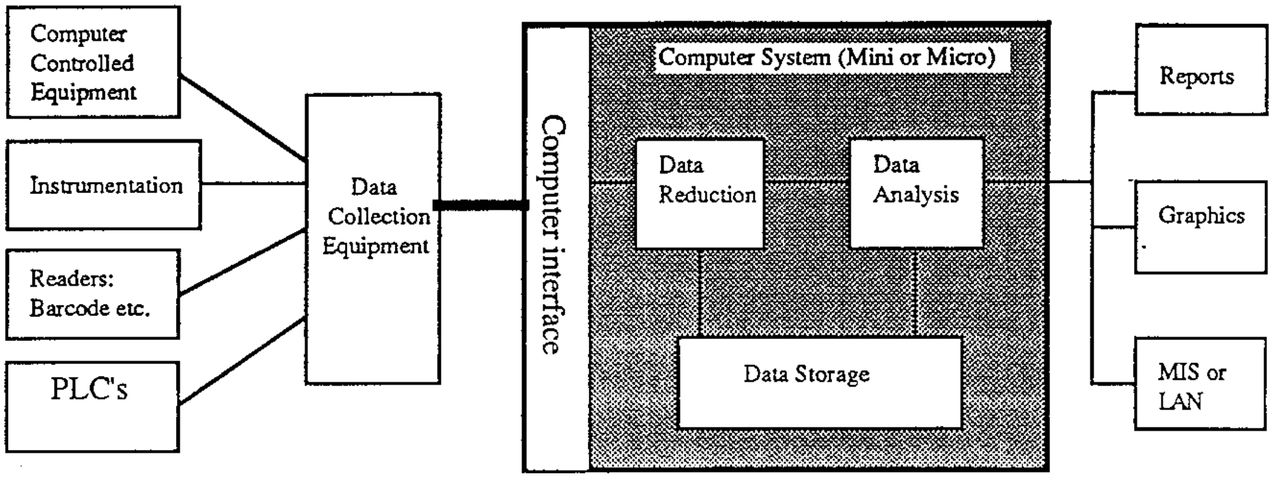
- ***Data Collection Systems***

  A data collection system is typically a stand alone computer system which is designed to operate in an industrial environment. It typically has a simple user interface and has an electrical interface to the electronic signals.

- ***Communication Interface Between Data Collection* System and the computer (typically IBM AT).**

  This interface normally consists of an RS232/RS485 cable and special communication software on each device. The interface can also be implemented through a modem or radio link so that the data collection system can be located in an location remote from the computer. Examples of this are given in the following case studies:

Fig. 1 Layout of Computerised Data Capture System



The Design, Development and Installation of Computerised Data Capture Systems requires expertise in many technological areas. The above diagram shows a typical layout of a Computerised Data Capture System. The skills required to implement such a system are:

Hardware
- Instrumentation
_ PLC's
_ Electonics Design
- Microcomputer and minicomputer hardware
- Data collection equipment.

Software:
- PLC Programming
- Microcomputer software
- Minicomputer software

Communications:
- interface to instrumentation
- interface between data collection equipment and computer
- interface between microcomputer and minicomputer.

Systems Design and Integration

TABLE. 1

Parameters Which Can Be Measured By Data Collection Systems.

Industrial Measurements

Barcodes
Product Counting
Machine Down-time
Manual Data
Temperature
Pressure
Weight
Flow Rate
Liquid Level
Distance
Tilt
Shaft Position
Torque

Environmental Measurements

Conductivity
Dissolved Oxygen
Electrolysis
pH
Turbidity
C02
Chlorine

Electrical / Energy Data

Voltage (AC or DC)
Current (AC or DC)
Electrical Energy kWh
Power Factor
Reactive Power
Electrical Harmonics

Meteorlogical Data

Wind Speed
Wind Direction
Relative Humidity
Solar Radiation
Ambient Temperature
Soil Temperature

For all of the above Hyperion uses standard 'off-the-shelf' components.
Hyperion also has the skills to custom design instruments or interfaces to instruments.

- *Computer System (IBM AT, MAC etc.)*

The computer system will include:

- the communication software outlined above.
- software to convert the data into format suitable for analysis.
- a data storage procedure
- a data analysis software.

- **Management Reporting:**

The data which is collected is converted into a format which can be used as management reports. These can occur in a number of formats.

a) **Real Time Monitoring.**

The measurements can be monitored in real time on the computer. This can be used to monitor remote processes, test processes or to supervise continuous processes.

b) **Graphical Displays**

Graphics can be used to examine trends or to mimic the layout of a plant or process.

b) **Text Reports**

Data Collection Systems are typically used to generate two types of reports:

- A management report which summarises the main results e.g. pollution levels, total effluent discharged etc.
- Exception reports which highlighted problems e.g. pH level exceeded, etc.

The reports can be generated on request, automatically at pre-set times or automatically when specified events occur eg. .when pollution levels are exceeded.

c) **Alarms**

Alarms can be generated in a number of ways.

- audible or visual alarms at locations throughout the plant.
- alarms on the computer system (audible or flashing screens).
- Event printouts.

e) **Interface to Management Information Systems.**

In companies where networks are installed the data collection systems can be interfaced to the network and data can be sent to specific computers or to specific applications (e.g. energy management software).

3. APPLICATIONS OF DATA COLLECTION SYSTEMS:

The most common applications of data collection systems are in the areas of:

- Quality Control
- Environmental Monitoring
- Research of new products or processes.

In quality control the main application is in Statistical Process Control (SPC). Data which is collected from the process or from sample measurements can be stored, analysed and displayed graphically.

In environmental monitoring the data is collected and stored in a format which will meet environmental regulations. The monitoring system would be used to alert personnel when environmental limits are exceeded and also to trace events by time, personnel or process.

In the research of new processes or products the data collection system is used to quantify the performance of the experiment and to provide data for analysis and optimisation. An example is provided in the following case studies.

4. FUNCTIONAL SPECIFICATION OF A DATA COLLECTION SYSTEM:

A data collection system is a tool which collects data from electronic sensors and converts this data into a format for reporting or for further analysis. In most applications the engineer will not have expertise in all of the technologies outlined in the previous section.

A functional specification is the information which is required by a designer of a data collection system. The criteria which must be defined are listed in table 2. When all of these are defined an accurate quotation can be given.

The procedure to define the functional specification can be summarised as follows:

a) Define the application in as much technical detail as possible.

b) Define all the possible measurements which could be made.

c) Define how the results will be presented. From this it will be possible to eliminate some of the measurements outlined above.

d) Define the characteristics of the measurements e.g.

- accuracy of the measurements
- sampling period
- sampling duration
- sensor location
- expected maintenance interval.

This functional specification is the basis for a detailed design and for an accurate quotation.

Table 2: Check List For Selecting Data Monitoring Systems

This checklist summarises the main criteria which should be considered when selecting a data monitoring system.

1. Sensors:

- Type of Sensor
- Principle of operation
- Accuracy
- Maintenance
- Cost

2. Data Logger:

- Manufacturer
- Accuracy (minimum 10 bit)
- Power Consumption
- Flexibility for expansion
- Details and cost of sensor interfaces
- Methods of data retrieval
- Ease of Programming

3. Computer Interface:

The options are:

- Direct Cable
- Radio Link
- Modem
- Floppy Disk
- RAM Card, RAM Pack or portable computer
- Combinations of the above options.

4. Computer Software:

- Analysis Capability
- Graphs and Report Capability
- High level language
- Easy to use
- Compatible with packages such as Lotus 123, D.Base III etc.

5. Systems Design and Installation:

The supplier should have expertise in:

- All of the areas 1 - 4
- Calibration procedures
- Training of operators
- Fault Finding in Hardware and Software

5. CASE STUDIES:

This section describes a number of data collection systems which have been designed and installed by Hyperion. In all cases Hyperion specified, designed, installed and commissioned the system.

Case Study 1: Bord Na Mona Biophore Effluent Treatment System

Biophore is a pollution control system developed by Bord Na Mona. The system uses filters made from bio-fibrous peat to extract impurities from gases released from industrial plant. The gas is pumped through a humidifier, into the filter modules, and the filtered gas is extracted using a fan. Hyperion supplied a measurement system to monitor the performance of the filtering system.

The Hyperion system measures the following values:

* Relative humidity, temperature, and pressure at the humidifier output
* Temperature and moisture content in the bio-filter
* Pressure at the bio-filter output
* Flow rate through the fan

As well as the measurement system, Hyperion designed the control system for the bio-filter.

From their headquarters in Newbridge, Bord Na Mona uses the Hyperion system to monitor the performance of six Biophore test units located around Ireland. A PC in Newbridge, linked by modem to the test units, can display the data in real time.

Case Study 2: Bord Na Mona Puraflo Effluent Treatment System

Puraflo is an effluent treatment system developed by Bord Na Mona. This system uses bio-fibrous peat containing micro-organisms to break down organic pollution in sewage. The treated sewage is then allowed to flow, via a sampling chamber, to a drain or into the soil. Hyperion supplied a measurement system to monitor the Puraflo system.

The Hyperion system measures the following values at the input and output of the filter:

* Dissolved Oxygen
* pH
* Flow rate
* Temperature
* Conductivity

Bord Na Mona has installed three Puraflo test units around Ireland. Like the Biophore system, the Puraflo measurement system uses a modem link to transmit the measurement data, in real time, from the remote sites to a PC at the Bord Na Mona headquarters in Newbridge.

Case Study 3: Cork County Council, Glashaboy Pollution Monitoring

At its Glashaboy waterworks, Cork County Council measures pH, dissolved Oxygen, and fish activity levels. Hyperion supplied a measurement system that uses the output from existing transducers at the waterworks.

In the Hyperion monitoring system, the measured data is transmitted continuously to a PC and the PC displays the measurements in real time. It also displays trends and generates an audible and visible alarm when pollution limits are exceeded.

CASE STUDIES:

Hyperion is an engineering company specialising in the design, installation and commissioning of automatic measurement systems.

The following is an example of projects which have been installed:

Application	Measurements	Client
Pollution Monitoring System	Ph, Dissolved Oxygen, Temperature	Cork Country Council
Meteorological Station (with radio link)	Windspeed, Wind Direction, Relative Humidity, Solar Radiation, Ambient Temperature	Bord Na Mona
Pump Performance System	Water Level, Pressure, Flow, Energy Consumption.	WIP, Germany
Flood Warning System	Water Level	Cork County Council
Battery Monitoring System	Voltage, Current, Temperature.	Internal Development
Biophore System (in progress)	Ph, Relative Humidity, Airflow, Temperature, Weight (Load Cell)	Bord Na Mona
Puraflo System (in Progress)	Ph, Conductivity, Dissolved Oxygen, Flow, Temperature	Bord Na Mona
Quality System For Plastics	Micrometers, Vernier Calipers, Height Guage, Weight	Cantrell & Cochrane
Fusion Experiment	High Frequency Voltage Signals	Farran Technology
Stock Control	Hand Held System	Heatmerchants

CONCLUSION:

Computerised Data Collection systems are tools which collect data and present the results in a format specified by the client.

This paper has provided a check list of criteria which should be considered when specifying a system and has given case studies to describe how these specifications have been put into practices.

Data collection systems cover many technologies such as instrumentation, computer hardware, software, communications systems etc. Companies such as Hyperion, specialise in this technology and can design systems to meet most clients requirements.

The success of a data collection system will not be judged on the hardware and software but on the clients definition of his requirements and on the application of the results generated by the system.

<u>HISTORY OF O.P.W. HYDROMETRICS</u>

The Hydrometric Service was set up in 1939 on the recommendation of the Browne Drainage Commission in an interim report to the Government. These early Hydrometric Stations were just staff gauges which were read daily. A programme was undertaken to upgrade these stations with autographic recorders in the 1940's and '50's. Due to the increasing interest in low flow Hydrology in the late 1960's the O.P.W. increased its monitoring and measuring of low flows and installed Hydrometric Stations at locations primarily for low flows, often at the behest of local authorities.

At present the O.P.W. Hydrometric Service has <u>300</u> stations nationwide with <u>180</u> of these having more than 20 years records of which <u>165</u> have 30 years or longer. The longest record is at Slane Castle on the Boyne, this station was installed in 1940.

Sixty of the 300 stations are strictly water level recording stations being installed to measure levels in estuary reaches or on lakes. Another 40 stations exist to monitor flood levels where it is not possible to calibrate the levels for the estimation of discharge. These locations are at manually operated controls or on stretches of rivers which are severely backwatered such as the most downstream stations on the tributary rivers of the Shannon or at locations with severe moving gravel.

A small amount of computerised data processing was carried out in the 1970's using the main frame computers at Kilmainham. This lead to the purchase of the section's own computer in 1979 and the full time processing of records. Of the 200 or so, stations which can be processed about 100 have been processed to date.

At present we have no electronic recording stations, however, these may be installed in future for the purpose of flood forecasting, etc.

River Problems that Effect the Estimation of Flow

When a Station's Flow measurements have been plotted there is normally a substantial scatter which cannot be totaly attributed to random variation and measurement errors. Problems at a measuring location may not show in the waterlevel record but take effect on the Flow Measurements, these are the subject of this section and may be devided into three main groups ....

1. Chronological changes, such as ....
   - Gradual changes in the channel, or the control section
   - Longterm accumulation of material
   - Gradual erosion of material

2. Seasonal changes, such as .....
   - Weed growth and decay
   - Seasonal deposition of material followed by its removal in the flood season

3. Human Interference such as ....
   - Dredging
   - Flood relief work
   - Construction of a weir or bridge

The following is an incomplete list of possible problems at measuring locations which should serve to demonstrate that unless the history and conditions at the station are known unacceptable errors can result. These can even render the record completely useless.

1. It normaly happens that stations with long records, i.e. in excess of 25 years were only setup to monitor peak levels and/or flows and the quality of the low flow record at these stations was not even considered because in Ireland low flows only became of interest in the early seventies. This often means that the stations were moved to better low flow locations in the river or the station was upgraded by the instalation of a measuring structure such as the "Crump-Style" control V-weir constructed by the O.P.W., for example 0709 Navan on the Boyne river.
Even when the original site was suitable for the recording of low flow the number of low Flow Measurements taken in the 1940's, '50's and early 1960's was not always adequate to fully define the controls on the low flows.

2. There are two main problems which occur when stations were installed upstream of old mill weirs, etc. These are ....

- Many of these weirs have horizontal cills which have very small depths of flow during drought conditions. Significant changes in low flow can cause water level changes less than 10mm and these cannot be detected by an instrument which records with an accuracy of +/-10mm.
- The gradual disrepair of the weir can lead to leaking and even breaches in the structure which cause a change in the control for the station and the need for more flow measurements.

3. Many Stations were installed to monitor a specific project where the exact location of the station is important. Such stations include those setup to monitor the flood levels in towns subject to flooding, for example, 2001 Bandon in County Cork. In the early seventies it was found that the quality of the low flow estimates was poor however the station could not be moved downstream of the town where a much better natural control existed. Station 2002 Curranure was installed there in 1976.

4. Due to the increased use of agricultural fertilizers and the enriching of our rivers by other forms of effluents the amount of weeds in rivers has increased to a point where, in some cases, any attempt to produce meaningful flow estimates has to be abandoned. No decent location may exist in the entire river stretch, for example, Station 1404 Clonbulloge on the Figile in the Barrow Catchment.

5. Catchments which have large deposits of gravel produce several major problems including ....

- They have, almost by definition, a control that changes from year to year which often displays strong seasonality.
- Major floods can cause a severe change in the gravel banks which form the control for the station, when this happens the station has to be completely re-rated by taking another complete range of Flow Measurements. Station 2311 BallyCarthy on the Lee in county Kerry had to be abandoned.
- Historic rights to locals for gravel removal means that the station can be left high and dry when the channel bed has been lowered by abstraction. In 1991 Station 0142, Ballybofey had to be moved and lowered and is now being re-Rated.
- It is not possible to record the amount of water that flows through the gravel bed of the river by a Surface Water Station, sometimes this can be avoided by placing the station just upstream of a rock shoal if it exists, however this is the exception rather than the rule. After failing to quantify the problem at Station 2271 Tomies Pier on Mucross Lake we had to install Station 2235, Laune Bridge downstream of it.

6. The instalation of a manual control or the revitalising of an abandoned control can cause one of two problems ....

- If the control is downstream
  non modular conditions can occur, i.e. a variable level discharge relationship, this means that it is impossible to produce estimates of flow and that the station must be moved.
- If the control is upstream
  the operating proceedures involve alternative holding and releasing of water which effects the flow of water past the station. A holding back of water for several hours during drought conditions can artifically reduce the Daily Mean Flow and as such, the true Annual Minimum Flow for the catchment can be considerably underestimated and over the years the entire set of low flow Analyses may become meaningless.

7. Rivers which cause considerable flooding often force the Recording Station to be located at a bridge because the road often restricts the river through the bridge and also provides access to the station in times of flood. The instrument can be either ....

- upstream of the bridge
  This ensures that the bridge gives good control to the Station's Rating however a bridge with several arches often gets blocked to some degree by debri during times of flooding and then it is not possible to give an estimate of the flood flow and the recorded level is too local to reflect the general flood levels in the valey.
- downstream of the bridge
  The record is less affected by the problems of dedri being traped by the bridge however the river flow is often at its most turbluent just downstream of of multi-arched bridge. The Low flow control is often not as good as that provided by the regular and often paved bridge openings.

8. Rivers which overtop their banks during flooding but which are still well contained by the rising ground of the valey are expected to produce a good and stable Flood Rating Curve. This is not the case if there is significant vegetetion on the flood plain, as the vegetation grows over the years it causes a different degree of retardation to the flood flows. This translates into a flood Rating Curve which changes with time, the effect does not always cause a disimprovement in the efficiency of the Rating, for example the branches of young trees interfeering with the flood waters cause considerable more retardation than their barks do 20 years later. Station 2621, Ballymahon on the Inny has been showing this type of effect over the last 30 years.
9. A location on a tributary can appear perfect as a measuring site however it can suffer from backwatering by the main river which can be several miles away. Station 1510 Ballyboodin on the Goul is severely backwatered and it is unlikely that a suitable location can be found on the river.

Man Made Water Courses and Measuring Structures

In comparison to natural channels Man Made watercourses generaly have a much greater depth of flow and hence a good depth to width ratio. The Rating power can be estimated using Fig. 1 or Fig. 2 depending on whether Critical or Uniform flow conditions occur.

The Shallow Depth Assumption

Many natural channels have a very small depth with respect to their width. When this holds the following guidelines may be followed ....

Channels which can be approximated, (below the water line), by a rectangular or trapezoidal shape have a Rating Curve power in the range of 1.5 to 1.7. This is the case with horizontal rock shoals. It is also typical of rivers which have steep banks such as the In-bank flow range for sandy or clay areas, this is due to the ease with which the river waters have been able to cut the channel.

Channels which can be approximated by a shallow parabola should result in slopes of about 1.5 to 2.2. The more pronounced the parabolic shape the bigger the rating power.

Also, rivers whose cross sections can be approximated by a triangle should have a Rating Curve with a power of between 2.5 and 2.7.

Often low flows in natural channels have parabolic or triangular or a hybrid section. These are also the shapes in the middle range of flows in hard gravely soils or rock where water has to wear away a channel. It should be noted that the steeper rivers have shapes which approximate towards the triangle rather than the parabola and therefore the power should tend to the upper part of the recommended range.

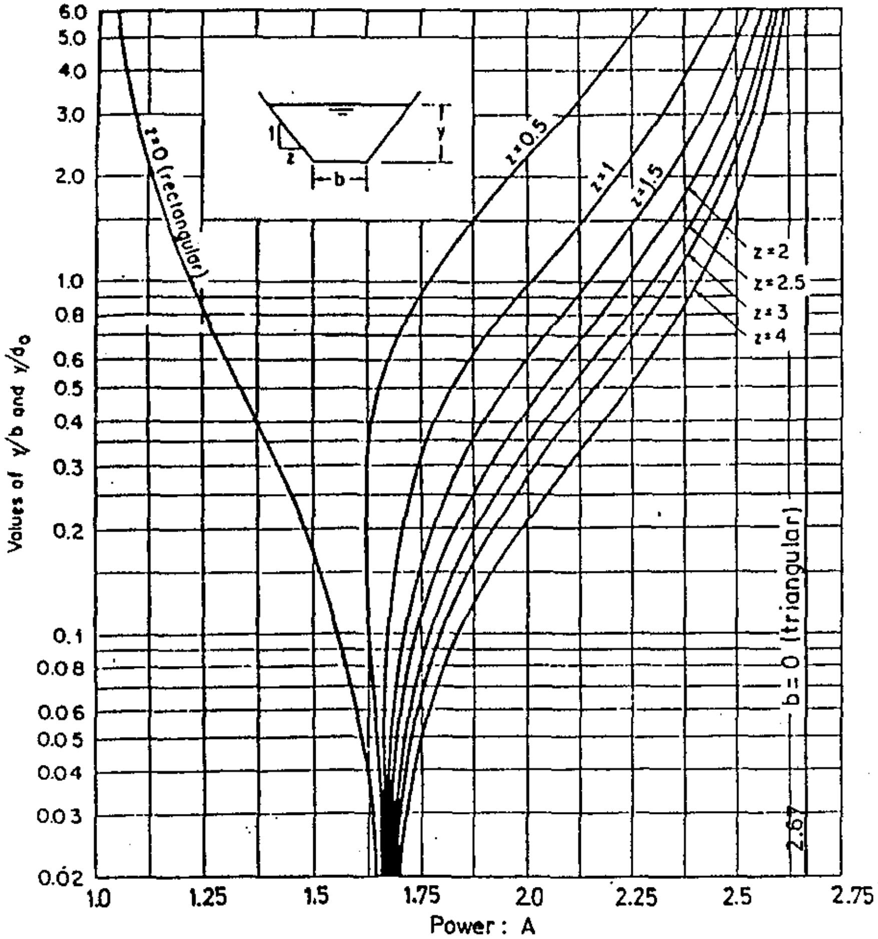


Fig. 1 Rating Curve Power for Uniform flow

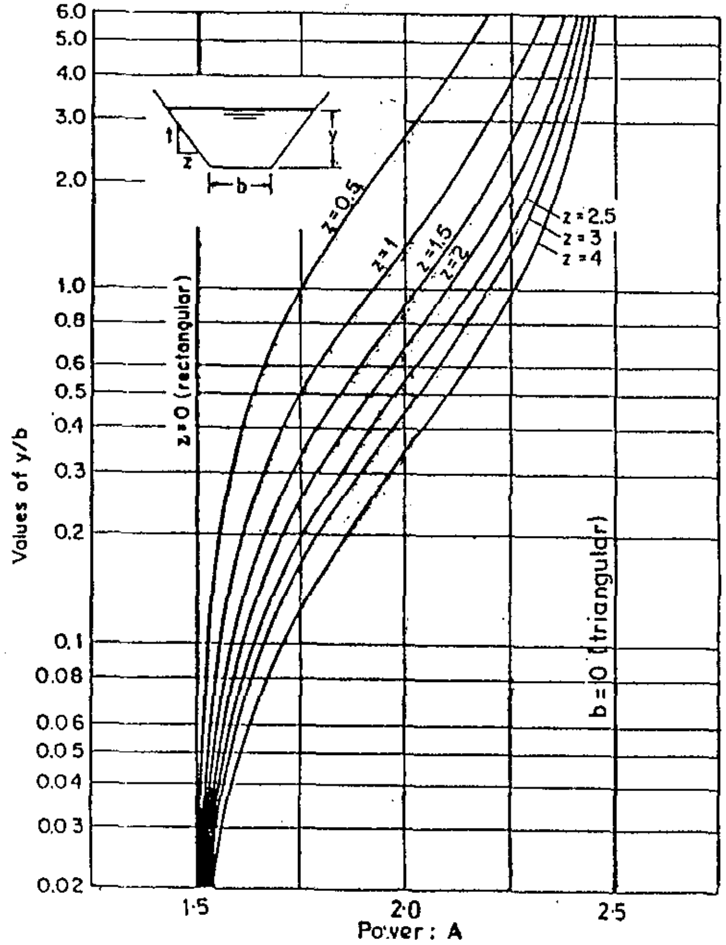


Fig. 2 Rating Curve Power for Critical flow

Development of a Rating Curve at an Example Station

The following will demonstrate the continuous interaction between site information and the construction of a Station's Rating Curves. We will make use of the flow Measurement record at an example station, flow measurements which indicated further complications other than those which we will be considering in this talk have been left out. The remaining measurements (table 1) are plotted in Fig. 3. There is considerable scatter at the low flow end, in general low flow measurements are very subject to secondary influences such as small changes in the river bed and seasonal changes such as weed growth. It takes a much bigger change to affect the high flows and due to this it is advisable to start examining the high flow end first. This will show up any long term changes to the site and can lead to an understanding of the background changes to low flows.

The example station is located at a bridge which has 3 river arches and a flood relief or storm arch. The vertical sides of these arches must constitute a control for the middle to upper flow ranges. The storm arch contributes in times of high floods so its effect on the upper end of the Rating will need to be investigated.

Examination of the middle to upper Flow Measurements shows that there are four distinct long term changes, these have been given separate symbols in Fig. 4. An assumption can now be made and tested "It is unlikely that a significant change occured to the bridge", if this is true then the Flow Measurements for each period will reflect the same hydraulic properties of the bridge and the only real differences between the periods will have been changes in the river bed, etc. This is tested as follows, the period which has the best quality and range of measurements is chosen as the control group, then, each other period (treated separately) has its measurements shifted up or down on the plot by the addition or subtraction of a set amount to their water levels until they plot within the band of the control group. This has been carried out and is displayed in Fig. 5, the trends of the data sets are the same so the assumption is considered proven. There has also been a considerable reduction in the scatter of the plot.

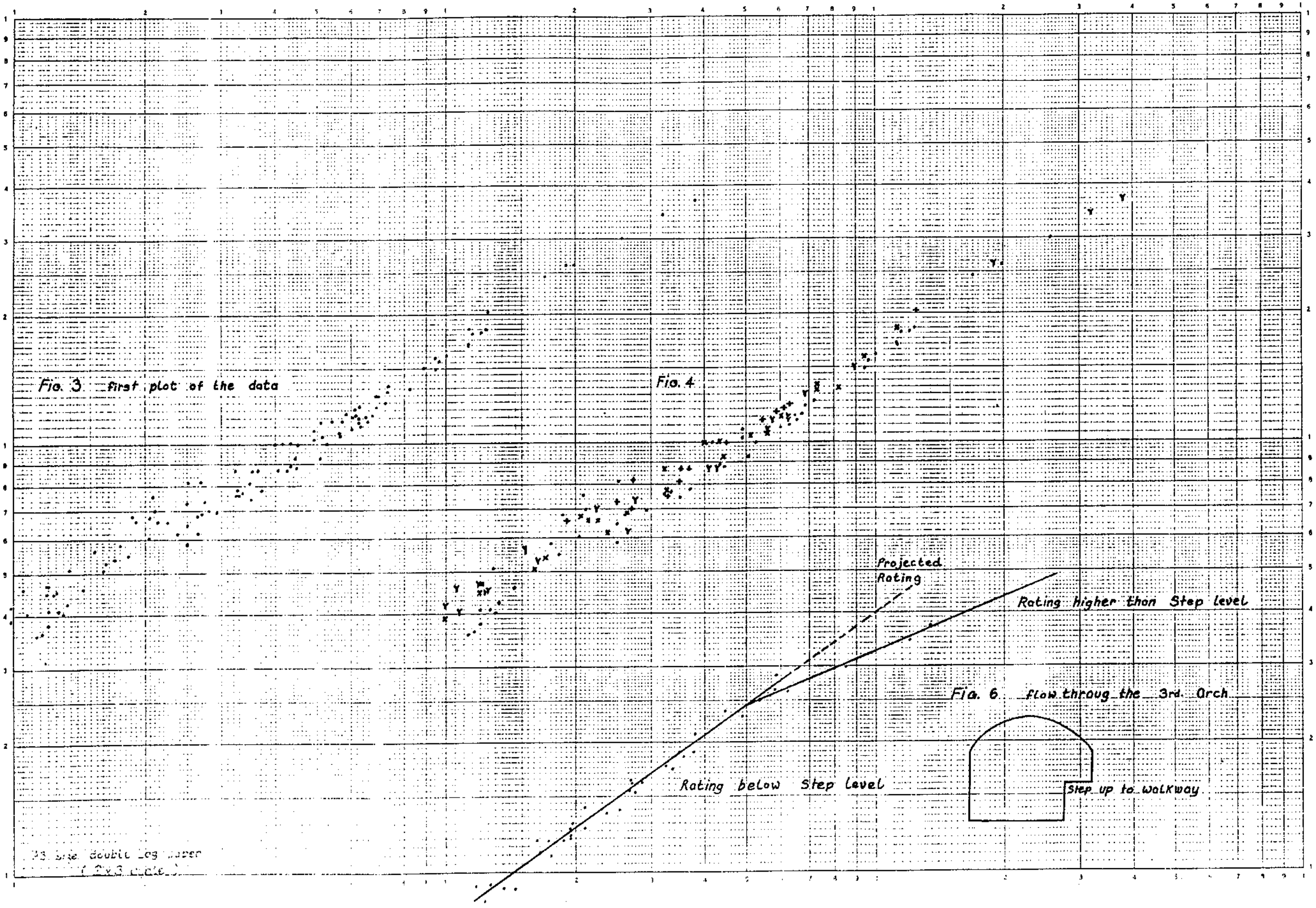
No.	Date	Level (metres)	Flow (m3/s)	
53	6-11-1978	.162	12.050	
54	25- 1-1979	.830	60.000	
55	23- 3-1979	.630	44.600	Symbol
56	20- 6-1979	.520	31.590	•
57	14- 8-1979	.565	25.180	
58	18- 1-1980	.910	64.890	
59	19- 2-1980	1.560	115.636	
60	18- 4-1980	.640	43.540	
61	21- 4-1980	.529	37.370	
62	7- 5-1980	.395	25.150	
63	20- 5-1980	.354	20.390	
64	26- 5-1980	.332	17.520	
65	26- 8-1980	.504	20.870	
66	4- 9-1980	.430	18.640	
67	1-10-1980	.753	41.580	
68	23-10-1980	2.200	170.280	
69	3-12-1980	.775	49.150	
70	18- 3-1981	.970	68.850	
71	2- 4-1981	1.046	69.640	
72	24- 4-1981	.430	35.210	
73	25- 5-1981	1.240	94.480	
74	11- 8-1981	.175	13.320	
75	18- 8-1981	.153	12.950	
76	21- 8-1981	.160	12.670	
77	25- 8-1981	.130	12.010	
78	1- 9-1981	.123	11.600	
79	8- 9-1981	.120	11.250	
80	20-10-1981	.826	49.100	
81	22-10-1981	.495	35.180	
82	15-12-1981	1.600	123.480	
83	2- 2-1982	.915	67.360	
84	4- 3-1982	1.310	96.340	
85	1- 4-1982	.680	50.690	
86	19- 8-1982	.449	21.020	
87	9- 9-1982	.260	13.380	
88	3-11-1982	1.360	100.030	
89	4- 1-1983	1.465	112.830	
90	11- 4-1983	1.000	72.130	
91	13- 5-1983	1.560	121.350	
92	27- 5-1983	.750	52.490	
93	24- 6-1983	.447	29.370	
94	20- 7-1983	.301	18.260	
95	11- 8-1983	.211	14.400	
96	3-10-1983	.430	26.420	
97	10-10-1983	.877	50.900	
98	1-11-1983	.510	32.490	
99	17-11-1983	.335	24.990	
100	10- 1-1984	.880	65.790	
101	8- 2-1984	2.730	256.700	
102	9- 2-1984	2.340	198.400	
103	1- 3-1984	.850	63.010	
104	26- 3-1984	1.440	112.570	
105	28- 5-1984	.290	17.000	Symbol
106	7- 6-1984	.410	22.590	X
107	26- 6-1984	.260	16.110	
108	1- 8-1984	.140	16.890	
109	30- 8-1984	.140	9.970	
110	9-11-1984	1.130	73.090	
111	11-12-1984	.790	51.370	
112	28- 1-1985	1.340	94.590	
113	7- 2-1985	1.609	112.110	
114	23- 4-1985	.620	42.680	
115	13- 5-1985	.440	27.130	
116	10- 9-1985	.745	39.940	
117	11-10-1985	.760	43.130	
118	16- 1-1986	1.080	73.200	
119	5- 2-1986	.745	48.000	
120	3- 4-1986	.800	56.410	
121	18- 4-1986	.550	35.050	
122	1- 5-1986	.535	32.649	
123	15- 5-1986	.910	60.400	
124	23- 9-1986	.425	21.073	
125	3-11-1986	.680	44.460	
126	20- 1-1987	1.340	94.189	
127	10- 2-1987	1.100	82.230	
128	14- 4-1987	.920	61.550	
129	15- 5-1987	.370	23.710	
130	10- 6-1987	.410	21.408	
131	12- 8-1987	.220	11.692	
132	24- 9-1987	.625	32.380	
133	4-11-1987	.500	32.803	
134	10-12-1987	.450	27.951	Symbol
135	16-12-1987	.750	45.044	+
136	10- 2-1988	1.780	125.424	
137	30- 3-1988	.930	58.664	
138	14- 6-1988	.410	19.037	
139	20- 7-1988	.481	24.916	
140	25- 7-1988	.570	27.257	
141	22-11-1988	.620	35.360	
142	13-12-1988	.620	36.858	
143	23- 1-1989	.880	54.430	
144	26- 1-1989	.984	63.007	
145	14- 2-1989	.960	61.142	
146	27- 4-1989	.560	34.977	
147	5- 7-1989	.220	11.794	
148	25- 7-1989	.170	9.927	Symbol
149	16- 8-1989	.280	16.234	Y
150	24-11-1989	.485	27.536	
151	7- 2-1990	3.425	378.274	
152	8- 2-1990	3.170	319.512	
153	15- 2-1990	2.370	190.497	
154	13- 8-1990	.205	12.575	
155	22- 9-1990	.155	10.716	
156	22-11-1990	.820	56.130	
157	1- 2-1991	.900	62.580	
158	25- 2-1991	1.260	89.460	
159	14- 3-1991	.885	62.780	
160	31- 7-1991	.315	15.270	
161	11- 9-1991	.200	12.346	
162	19- 9-1991	.210	10.540	
163	9- 1-1992	1.055	68.501	
164	7- 2-1992	.370	26.467	
165	3- 4-1992	.620	42.792	
166	19- 8-1992	.450	22.357	
167	29-10-1992	.620	40.830	
168	14-12-1992	.885	57.500	

	Date	Level	Flow
Smallest Measured Flow	5- 9-1975	.090	6.760
Largest Measured Flow	7- 2-1990	3.425	378.274

Produced by the Hydrometric Section, **OFFICE OF PUBLIC WORKS**

Table 1

Graph Data Ref 5823 Log 2 Cycles x 3 Cycles



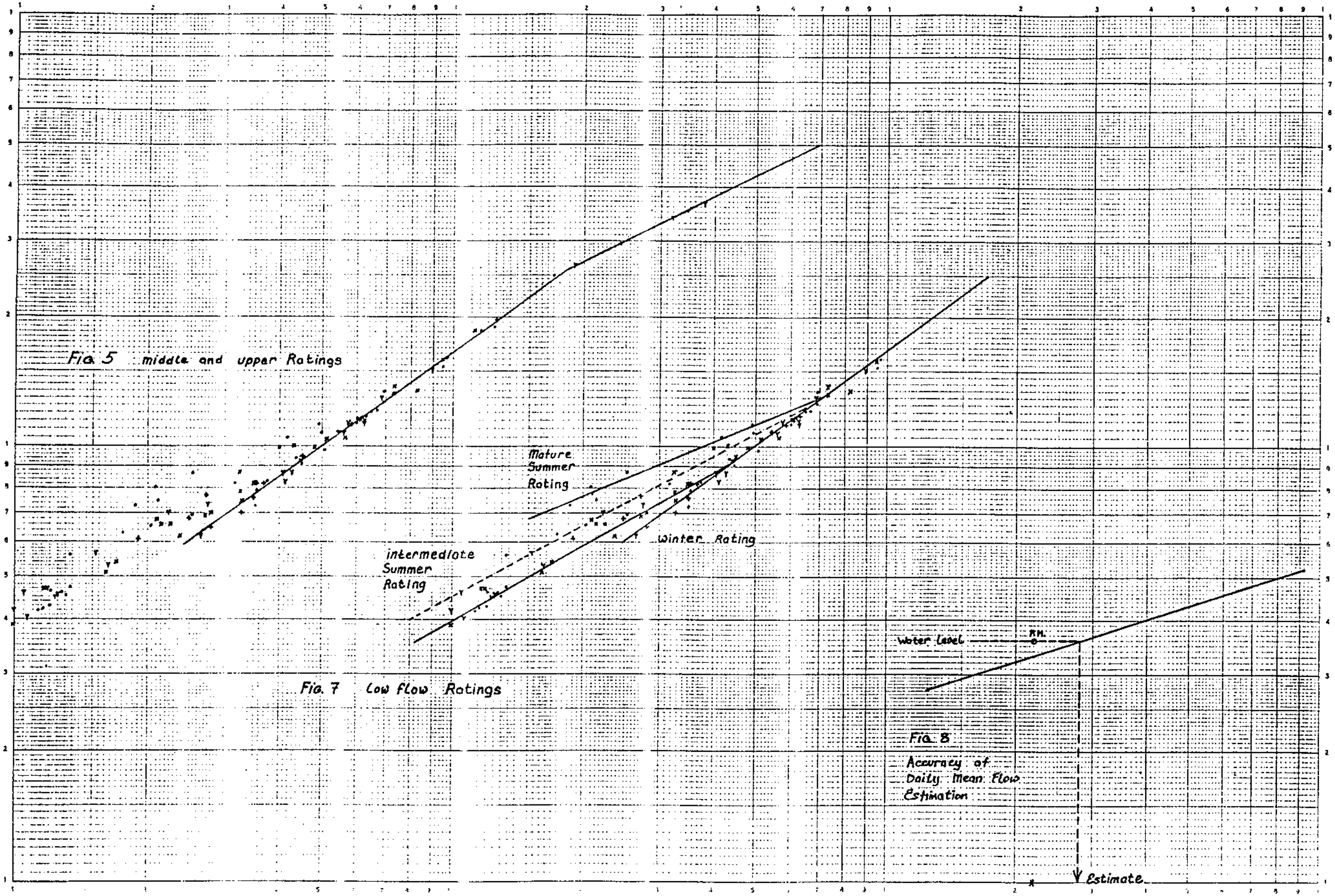


Fig. 5 middle and upper Ratings
Mature Summer Rating
intermediate Summer Rating
Winter Rating
Fig. 7 Low flow Ratings
Water Level
R.M.
Fig. 8
Accuracy of Daily Mean Flow Estimation
Estimate

There is a definite change in the slope of the plot close to the top end of the measured range which must be investigated. It takes a considerable change in the cross sectional properties to cause a major change in the flood flow Rating. When the original sheets upon which the flow Measurements were recorded were examined to find the contribution made by the storm arch is was found that its flow is very small and can not account for the change. The Measurement Sheets also showed that there is a walkway going through the third arch of the bridge above this the flow width is considerably bigger. The flows that have been recorded through the third arch were then examined in isolation resulting in Fig. 6. A pronounced change in its Rating is visible at the level of the walkway and this is enough to account for the change in the station's upper Rating which can now be drawn along with an estimate of the middle Rating, (Fig. 5). It can be seen that the middle Rating could be drawn down into the group of lower Flow Measurements which have the higher flow values.

The Low Flow Measurements can now be examined. The long term effects which were picked up in the examination of the upper Rating Curve have already been taken into account. Now, we need to check for seasonal effects. Examining the measurements on a month by month basis shows that a seasonal effect is present. The river is at its most efficient in the winter months then the Spring/Summer measurements show the river becoming progressively less efficient up to the least efficient condition in August after which time the river increases in efficiency until the channel has reverted to the winter condition.

A series of low flow Ratings can now be drawn showing a progression in river control ranging from the efficient Winter Rating up through a series of Intermediate Ratings to the Mature Summer Rating and back through these Intermediate Ratings to the efficient Winter Rating (Fig. 7).

It could be considered at this point that the Ratings have been developed for the station. This is not so. An examination of the Flow Measurements shows that some years reached the mature Summer Rating and others did not, either one of two options can account for this ....

- not enough measurements were taken in each summer to prove that the river did get to the mature Summer Rating
- all summers did not get to the mature Summer Rating

An examination of the Flow Measurements shows that some years which have mid summer measurements did not reach the mature Summer Rating and their Ratings are well defined. However, other years which had high June and July or high September and October measurements strongly indicate that it was reached.

This poses the first real Processing dilemma. Can we, based on this, put in the mature Summer Rating for these years even though no measurements were taken to prove it. This is a very vital point because the estimation of the Annual Minimum flow for each of these years is dependant on it and the considerable difference in estimates that would result from either decision will have an effect on the estimates of Return Period Low flows and on all other low flow analyses.

The argument in favour of producing the Rating without any Flow Measurement is that the procedure which has lead to this considers the data to reflect the inherent conditions of the river which do not disappear just because no Flow Measurements were taken over a two month period in a given summer.

If another Hydrometric Station exists on the same river a comparison with its processed record on a year by year basis may clarify the problem.

Another very important point about Rating Curves can be shown from this station's measurements. When the flow measurements, of any year, taken from Spring into high summer are picked out in the plot they do not follow down along any of the low flow Ratings, instead they drift progressively from the efficient Winter Rating passing through the Intermediate Ratings to the least inefficient Rating for that summer. Then why isn't the line through the points the Rating for that summer and wouldn't this lead to a more accurate assessment of the flow in the river? The answer lies in understanding that a Rating is the calibration over a range of water levels for a given control. In this example set of data the Low Flow control is not fixed in the manner that the cill of a weir remains fixed. The control is constantly changing and each of these Flow Measurements is only one point on a different Rating from the Rating that pertained when the previous measurement was taken. If a line was drawn through these points it would give you good estimates of flow as the summer flows recede, however the flows of any flood event and its recession would be greatly overestimated. This would then mean that the resulting flow estimates for much of the summer would be suspect.

Accuracy of the Daily Mean Flow Estimates

When the Daily Mean Flows have been produced it is generaly believed that they are the best estimates of flow for each individual day. This is not the case and it can be shown quite simply by returning to the plot of Flow Measurements and Rating Curves. The following argument will be more clearly understood if we limit our attention to low flows due to the small changes that occur in the water level and flow throughout a drought day. It would seem reasonable that the Daily Mean Flow estimated for a specific day in which a Flow Measurement was carried out would agree with the measurement, however when they are compared they are seen to disagree. The answer is simple, the specific Flow Measurement did not fall on, or near, the Rating Curve (fig. 8).

This is often the case and it leads to the question whether the set of Daily Mean Flows are the best that can be produced or not? The solution to this lies in understanding that in the overall context of the year's data they are the best because the Rating curve is the best that fits the data. If further refinements to the Ratings were possible they would have been picked up when the Ratings were being developed. There is a point reached where further refinement of a Rating becomes harmful, this happens when only a small number of Flow Measurements indicate a minor change in the subtle changes of the river's controls. Relying too heavily on a specific Flow Measurement only leads to estimates which are prone to the errors inherent in that Flow Measurement.

Should the Specific day have its estimate changed to agree with the Flow Measurement? If we were to change it then it would have lost its consistency with the neighbouring Days' estimates and how much should we change these by? and how many days should have their Daily Mean's changed? Even if this was possible the overall balance in the full year's data has been upset and the Statistical qualities of all subsequent Analyses are lost.

Because of these arguments we refer to our system as a 'General Processing System' in which the integrity of the follow on analyses is safeguarded. It is not a 'Specific Processing System' where the emphasis is on the Estimates on Specific days.

INFORMATION PRODUCED

Hydrometric records are a finite sequence of observations which can be seen as a sample of the long sequence of flow at the location. This data is used to produce empirical estimates of the true unknown statistical quantities. Estimates based on short records can be expected to differ greatly from the true statistic and the longer the sample the more accurate the empirical estimates.

The following is a selection of the general information that can be produced from processed Hydrometric data.

Level Hydrograph

The Level Hydrograph is a plot of level against time generally over a full year. The graph for any processed year can be produced ....

- on its own
- superimposed on other years' Hydrographs
- superimposed on the overall average Hydrograph produced from the record.

Simple Multi-site Analysis

When there is more than one Station on a river stretch which does not have any significant intermediate flow from tributaries simple multi-site analyses can be carried out. Comparison of the Steady part of their hydrographs, where there is not considerable rise or fall in waterlevels, gives an understanding of ..

(a) Travel Time Relationships, (the Propagation of a flood)

These are calculated by examining the propagation of the flood peaks along the river stretch resulting in a plot of peak level against travel time. The Mean Travel Time of a reach is often indicated on the Stage Relation Curve.

(b) Stage Relation Curves, (the Deformation of a flood)

This is of particular interest for slow rivers. It shows the deformation of the flood peak as it passes the stations in the river reach. Stage Relation Curves also allows the following to be evaluated ....

1 The mean slope of the water surface between the stations for each river stretch.

2 This slope can then be used to find the Mean Hydraulic Roughness for the river reach.

Flow Measurements

The Flow Measurements at any station can be supplied (Table 1).

Daily, Monthly and Yearly Mean Flows and Monthly Lowest Flows

This consists of a page per year of Daily Mean Flows and a summary page of Monthly and Yearly Mean Flows and a summary of the Monthly Lowest Daily Mean Flows (Tables 2, 3 and 4)

Probability of Occurrence on a Given Day

When hydrographs for many years are available at a station the probability of equalling or exceeding certain water levels or discharges for any day of the year can be studied. This type of analysis is only of use when there is a pronounced seasonality in the character of a flow regime or in manually controlled waters such as releases from a reservoir and the remaining levels in the reservoir.

Daily Mean Flows m3/s Data sheet for station No. 1611 Clonmel (Suir Catchment)
Station's Catchment Area is 2173. Km2 RIVER ---- Suir

	Date	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	1	34.4	23.7	52.2	52.0	50.5	51.1	17.9	15.6	36.2	23.9	27.6	67.0
	2	32.8	23.0	42.7	48.4	45.1	29.8	17.1	15.4	40.5	22.7	28.0	99.3
	3	32.9	22.4	38.6	40.7	40.8	102.1	20.3	15.9	36.9	21.4	29.7	83.4
	4	39.0	22.7	36.7	37.4	38.6	126.6	25.3	15.6	37.4	20.5	28.5	82.8
	5	64.9	22.3	34.6	35.7	41.2	73.0	20.6	20.7	34.0	19.5	26.7	80.0
	6	71.8	22.3	37.1	45.7	39.0	47.7	18.1	17.3	34.6	18.9	25.9	91.1
	7	69.1	22.0	95.9	47.7	36.3	38.3	16.7	15.6	44.7	18.1	25.5	107.5
	8	85.1	21.8	68.4	47.8	34.8	33.1	16.2	15.2	31.7	17.5	24.5	96.9
	9	72.5	25.8	64.0	41.4	34.2	30.5	18.4	14.9	27.9	17.1	35.7	86.6
	10	59.1	26.5	66.8	37.8	34.2	31.5	17.4	14.8	25.6	16.6	43.4	76.0
	11	50.3	25.5	61.3	36.0	37.3	33.9	16.6	14.4	117.0	16.2	47.5	67.9
	12	47.0	36.5	88.0	35.9	50.9	28.8	17.1	23.6	93.3	15.7	49.7	71.7
	13	43.7	41.0	83.3	36.1	43.9	25.8	17.1	24.7	140.2	15.2	46.7	65.0
	14	40.8	40.2	70.9	45.1	37.4	24.2	23.6	37.3	111.4	15.2	49.7	60.9
1992	15	38.1	38.0	64.1	66.5	33.9	23.2	19.1	26.6	96.3	14.9	48.2	57.9
	16	36.1	33.2	56.2	49.6	31.2	22.4	17.1	40.6	83.3	14.2	44.5	70.6
	17	33.9	31.6	50.6	42.9	29.9	21.6	19.0	28.5	68.8	13.7	50.7	69.3
	18	32.4	34.3	48.6	41.5	28.5	20.8	17.7	26.0	57.7	13.7	61.7	138.7
	19	31.1	33.1	46.1	37.9	27.7	20.1	23.0	22.6	47.2	13.5	61.2	96.6
	20	30.5	30.7	44.9	36.0	27.0	19.7	18.4	20.6	40.7	13.1	50.7	77.9
	21	30.0	29.4	48.7	35.3	26.4	19.2	20.1	19.3	35.5	13.0	50.0	67.8
	22	29.0	28.7	82.1	34.6	25.7	18.6	17.2	50.4	31.9	13.1	74.1	67.3
	23	28.1	31.0	82.6	43.8	25.2	18.3	24.1	53.0	29.4	16.9	83.0	64.2
	24	26.8	32.8	68.1	108.2	25.0	18.2	40.7	32.8	28.9	23.8	84.4	59.0
	25	27.6	32.5	54.8	82.1	26.1	17.9	25.4	27.8	29.5	41.2	101.7	55.0
	26	31.6	41.5	50.2	74.7	43.9	17.5	25.9	24.4	27.2	63.3	81.7	51.7
	27	29.0	52.5	46.1	65.1	28.9	17.1	21.5	27.6	26.9	44.0	74.2	49.1
	28	27.2	49.6	41.7	56.3	25.3	16.7	18.7	27.4	28.0	45.9	74.1	46.6
	29	26.1	40.6	40.2	49.6	25.7	16.3	17.6	24.3	24.9	40.6	66.0	44.2
	30	25.3		41.3	49.5	26.1	16.1	16.8	49.6	25.3	34.9	65.1	42.8
	31	24.3		41.8		35.0		16.0	43.7		30.3		41.0
Lowest	D.M.F.	24.3	21.8	34.6	34.6	25.0	16.1	16.0	14.4	24.9	13.0	24.5	41.0
Highest Discharge	m3/s	95.2	67.9	111.1	123.9	61.7	146.3	51.2	92.2	147.7	77.2	111.8	147.3
	Date	8	27	7	24	32	3	24	22	13	26	25	18
Monthly Mean	m3/s	40.3	31.6	56.4	48.7	34.1	32.7	20.0	26.0	49.8	22.9	52.0	72.1
	/100 km2	1.9	1.5	2.6	2.2	1.6	1.5	.9	1.2	2.3	1.1	2.4	3.3

Annual Mean Flow 40.54 m3/s (1.87 m3/s /100 km2) Lowest D.M.F 12.967 m3/s Highest Discharge 147.7 m3/s

Produced by the Hydrometric Section, **OFFICE OF PUBLIC WORKS**

Table 2

Mean Flows m3/s — Data sheet for station No. 1611 — Station's Catchment Area = 2173. km2 — Clonmel (Suir Catchment) — RIVER ------ Suir

Year	Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	46.33	78.48	36.70	35.88	35.46	32.82	16.82	17.54	11.10	28.26	42.12	81.22	138.20
1969	36.38	150.16	58.73	31.32	31.10	27.32	19.53	13.43	10.09	10.43	10.60	24.78	49.36
1970	40.76	69.77	108.16	41.75	39.75	29.82	14.62	14.07	17.53	18.80	13.86	73.99	52.95
1971	26.82	53.04	42.08	30.32	22.08	14.69	16.82	11.01	34.77	12.78	21.63	32.37	30.94
1972	46.47	85.09	94.40	63.92	44.70	35.11	30.35	23.27	22.67	11.08	10.25	47.01	91.11
1973	39.36	75.09	68.23	35.11	18.35	28.54	17.02	24.17	17.22	20.85	31.35	35.00	102.06
1974	48.04	136.46	116.63	40.94	11.90	25.12	14.36	14.39	16.57	67.12	30.09	41.40	66.25
1975	39.49	106.49	70.36	41.28	25.35	23.17	13.08	14.39	9.05	21.50	52.45	49.39	48.82
1976	36.92	65.61	70.50	63.03	31.91	32.72	22.08	16.64	8.36	11.87	45.49	31.15	44.21
1977	47.87	62.38	113.08	74.36	39.41	21.19	11.14	12.92	16.77	17.40	46.98	74.25	89.30
1978	47.85	63.24	92.73	70.93	54.54	18.85	15.81	16.38	31.07	13.92	13.42	31.28	153.96
1979	55.93	66.40	76.05	74.64	49.74	54.90	47.15	11.49	12.46	18.95	62.58	81.03	116.88
1980	56.83	92.25	110.52	67.47	46.87	20.29	12.99	20.76	42.44	43.94	75.25	71.50	79.53
1981	54.82	60.76	65.24	122.50	49.43	63.52	49.93	23.15	13.80	26.29	43.54	43.85	95.17
1982	60.76	95.23	89.06	97.21	39.80	22.67	39.02	15.04	11.54	24.14	73.83	123.69	100.06
1983	55.94	92.10	81.35	69.20	60.76	85.84	40.40	18.09	14.62	34.50	56.43	32.77	85.85
1984	50.18	139.13	126.12	54.55	44.71	20.80	19.89	12.37	11.21	11.74	25.21	60.82	78.42
1985	N.A.	49.65	63.68	60.38	62.55	29.20	28.75	23.16	63.54	41.25	34.28	30.63	N.A.
1986	57.01	N.A.	35.68	48.85	43.30	56.31	30.47	37.14	84.07	29.02	26.76	78.58	126.28
1987	38.70	71.31	50.35	53.05	68.04	21.98	21.68	14.59	11.76	23.20	43.48	43.09	43.10
1988	58.52	142.23	120.48	57.99	30.61	35.37	20.46	29.78	23.77	30.49	118.36	49.83	43.53
1989	37.22	51.91	53.82	86.04	48.13	20.16	17.82	11.55	14.09	16.45	26.38	41.13	59.93
1990	45.08	85.59	177.36	61.68	27.40	16.42	10.99	13.33	10.38	9.23	40.94	44.60	52.96
1991	45.49	95.81	57.47	72.94	64.71	26.75	20.50	16.98	16.03	13.42	29.19	83.15	50.10
1992	40.54	40.34	31.55	56.42	48.71	34.06	32.66	20.03	26.01	49.76	22.86	52.01	72.13
Lowest	26.82	40.34	31.55	30.32	11.90	14.69	10.99	11.01	8.36	9.23	10.25	24.78	30.94
Highest	60.76	150.16	177.36	122.50	68.04	85.84	49.93	37.14	84.07	67.12	118.36	123.69	153.96
Average	46.39	84.52	80.41	60.47	41.57	31.90	23.37	17.83	22.04	24.26	39.89	54.34	77.96

Table 3

Produced by the Hydrometric Section, OFFICE OF PUBLIC WORKS

Min. Flows m3/s — Data sheet for station No. 1611 — Station's Catchment Area = 2173. km2 — Clonmel (Suir Catchment) — RIVER ------ Suir

Year	Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	9.28	40.98	21.47	16.34	18.82	19.94	14.00	11.66	9.28	9.93	23.72	40.55	49.47
1969	8.48	55.13	38.16	19.61	18.75	21.48	15.96	10.54	8.67	8.48	9.59	9.86	17.79
1970	8.28	20.97	66.78	26.74	21.47	23.31	12.24	9.15	9.64	9.24	8.28	17.33	26.16
1971	7.41	20.83	27.95	16.07	14.20	12.55	11.14	7.41	14.58	10.05	9.33	14.24	18.39
1972	6.37	21.19	43.54	33.71	19.31	19.55	20.76	15.26	15.82	7.28	6.37	9.88	45.32
1973	7.48	33.32	48.07	16.55	10.96	12.07	14.94	17.91	9.74	7.48	13.85	13.51	49.44
1974	8.13	51.19	54.28	17.35	8.69	8.13	10.98	11.09	10.96	28.89	20.94	21.82	42.30
1975	6.75	43.07	50.45	26.59	21.26	17.88	8.71	8.57	7.16	6.75	19.60	33.89	25.97
1976	5.52	32.10	46.66	33.54	21.04	19.64	16.77	9.97	6.57	5.52	14.26	18.75	26.66
1977	9.57	27.75	59.81	45.05	23.61	11.82	9.57	10.92	10.43	10.58	19.70	34.39	32.67
1978	8.99	35.15	45.48	51.27	23.91	10.71	12.95	10.12	17.93	10.41	8.99	11.44	70.82
1979	7.05	52.99	47.55	49.26	33.87	24.96	18.31	7.09	7.05	10.83	16.38	52.82	67.93
1980	9.44	61.57	62.64	49.09	32.15	12.42	11.43	10.89	10.20	9.44	26.30	44.18	38.93
1981	10.80	39.67	41.69	69.84	30.58	28.40	27.06	17.74	11.81	10.80	29.28	23.69	38.25
1982	8.13	56.20	58.16	56.02	25.10	16.77	14.87	8.54	8.13	11.22	29.94	73.30	58.81
1983	11.21	56.44	43.14	49.96	37.97	48.06	26.47	14.29	11.21	12.99	25.61	23.70	27.64
1984	8.37	61.68	63.58	31.39	29.06	17.17	13.32	9.27	8.50	8.37	9.09	26.38	49.40
1985	N.A.	24.70	32.64	33.99	30.17	21.71	15.98	17.55	21.47	21.72	17.66	16.62	N.A.
1986	N.A.	N.A.	20.81	19.76	29.67	31.03	17.54	21.05	30.64	17.78	12.75	32.99	60.21
1987	7.82	41.27	31.75	37.32	29.30	17.95	14.98	11.52	7.82	12.36	17.37	23.38	23.34
1988	13.31	86.16	47.09	30.27	21.13	17.86	13.31	18.04	17.25	15.06	28.91	31.13	30.43
1989	9.79	32.19	37.95	60.11	29.92	15.76	13.77	9.79	9.85	10.74	11.29	21.99	16.56
1990	7.57	55.07	121.24	32.65	20.10	13.16	7.57	7.94	8.67	8.20	13.61	22.05	18.24
1991	9.31	42.09	34.89	39.60	34.95	18.31	17.31	15.34	12.06	9.31	15.64	44.36	31.76
1992	12.97	24.26	21.81	34.57	34.57	25.00	16.06	15.96	14.43	24.92	12.97	24.54	41.00
Lowest	5.52	20.83	20.81	16.07	8.69	8.13	7.57	7.09	6.57	5.52	6.37	9.86	16.56
Highest	13.31	86.16	121.24	69.84	37.97	48.06	27.06	21.05	30.64	28.89	29.94	73.30	70.82
Average	8.78	42.33	46.70	35.87	24.82	19.43	15.04	12.30	11.99	11.93	16.86	27.47	37.81

Table 4

Produced by the Hydrometric Section, OFFICE OF PUBLIC WORKS

/EL DURATION CURVES in metres 1802 Ballyduff, (Munster Blackwater Catchment) RIVER Blackwater

›r	1%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	99%	Minimum Level	Maximum Level	Total Valid Days	Total Down Days
56	12.40	11.37	10.94	10.77	10.70	10.63	10.56	10.52	10.48	10.45	10.38	10.34	10.33	10.31	10.30	10.26	10.20	10.17	10.12	10.09	10.07	10.038	13.058	366.0	.00
57	Not Available																					9.859	13.658	326.3	38.67
58	12.69	11.66	11.27	11.09	10.95	10.85	10.78	10.73	10.68	10.64	10.59	10.55	10.51	10.48	10.44	10.41	10.37	10.32	10.28	10.24	10.17	10.153	12.992	365.0	.00
59	12.52	11.59	11.18	10.94	10.80	10.68	10.61	10.55	10.48	10.42	10.34	10.27	10.22	10.18	10.10	10.05	10.00	9.911	9.869	9.847	9.826	9.808	12.943	365.0	.00
60	12.61	12.03	11.69	11.40	11.17	11.01	10.88	10.80	10.73	10.67	10.61	10.53	10.47	10.41	10.34	10.29	10.25	10.20	10.17	10.13	10.07	10.048	13.223	366.0	.00
61	12.56	11.61	11.25	10.92	10.73	10.55	10.45	10.37	10.30	10.24	10.18	10.14	10.11	10.04	9.976	9.938	9.913	9.890	9.876	9.863	9.810	9.787	13.325	365.0	.00
62	12.07	11.23	10.91	10.75	10.65	10.56	10.48	10.42	10.36	10.32	10.27	10.22	10.18	10.15	10.12	10.11	10.08	10.06	10.04	10.03	10.01	9.990	12.830	365.0	.00
63	12.54	11.69	11.14	10.94	10.78	10.67	10.57	10.49	10.45	10.40	10.37	10.33	10.29	10.25	10.21	10.19	10.17	10.14	10.12	10.10	10.06	10.047	12.957	365.0	.00
64	12.72	11.50	11.07	10.79	10.64	10.54	10.48	10.42	10.39	10.36	10.33	10.31	10.28	10.24	10.22	10.19	10.17	10.15	10.12	10.10	10.06	10.022	13.202	366.0	.00
65	12.84	11.82	11.31	11.07	10.86	10.72	10.61	10.52	10.47	10.42	10.38	10.35	10.32	10.30	10.26	10.22	10.19	10.17	10.15	10.12	10.08	10.040	13.424	365.0	.00
66	12.63	11.95	11.52	11.23	11.05	10.86	10.71	10.61	10.52	10.46	10.41	10.33	10.27	10.23	10.20	10.16	10.12	10.08	10.04	10.00	9.947	9.921	13.014	365.0	.00
67	12.10	11.36	11.03	10.85	10.75	10.67	10.62	10.54	10.49	10.43	10.37	10.33	10.29	10.24	10.19	10.14	10.10	10.07	10.01	9.960	9.919	9.906	13.095	365.0	.00
68	12.73	11.52	11.09	10.80	10.67	10.64	10.56	10.49	10.43	10.35	10.30	10.25	10.20	10.17	10.13	10.11	10.09	10.07	10.05	10.01	9.976	9.964	13.765	366.0	.00
69	12.79	11.44	10.88	10.67	10.48	10.35	10.28	10.23	10.18	10.15	10.10	10.06	10.02	9.980	9.957	9.916	9.892	9.865	9.834	9.807	9.767	9.754	13.738	365.0	.00
70	12.36	11.62	11.15	10.87	10.73	10.58	10.46	10.37	10.31	10.26	10.22	10.18	10.14	10.12	10.11	10.07	10.03	9.997	9.965	9.952	9.940	9.927	12.679	365.0	.00
71	11.62	11.03	10.74	10.57	10.48	10.41	10.36	10.32	10.29	10.26	10.22	10.17	10.13	10.10	10.08	10.06	10.03	10.01	9.994	9.980	9.962	9.947	12.084	365.0	.00
72	12.48	11.77	11.28	11.05	10.91	10.79	10.64	10.52	10.44	10.38	10.31	10.27	10.23	10.19	10.16	10.13	10.09	10.02	9.977	9.939	9.917	9.905	13.081	366.0	.00
73	11.91	11.36	11.00	10.83	10.71	10.61	10.52	10.46	10.39	10.34	10.30	10.27	10.25	10.23	10.21	10.19	10.16	10.13	10.11	10.07	10.00	9.960	12.779	365.0	.00
74	12.92	12.02	11.43	11.05	10.78	10.62	10.49	10.39	10.32	10.26	10.21	10.17	10.14	10.08	10.03	9.987	9.944	9.883	9.853	9.827	9.799	9.781	13.336	365.0	.00
75	12.33	11.27	10.73	10.53	10.43	10.37	10.29	10.23	10.16	10.11	10.08	10.05	10.01	9.968	9.891	9.826	9.792	9.748	9.737	9.724	9.711	9.698	12.960	365.0	.00
76	11.81	11.11	10.71	10.59	10.51	10.43	10.37	10.28	10.21	10.17	10.12	10.07	9.981	9.931	9.891	9.844	9.802	9.767	9.732	9.696	9.677	9.672	12.844	366.0	.00
77	12.08	11.54	11.27	11.08	10.95	10.84	10.76	10.66	10.55	10.40	10.27	10.17	10.07	9.952	9.892	9.866	9.845	9.817	9.801	9.789	9.752	9.736	12.705	365.0	.00
78	12.85	11.68	11.12	10.93	10.84	10.73	10.62	10.53	10.39	10.22	10.11	10.01	9.951	9.916	9.897	9.882	9.869	9.857	9.842	9.813	9.749	9.747	13.722	365.0	.00
79	12.30	11.45	11.18	10.98	10.85	10.76	10.68	10.61	10.54	10.48	10.43	10.40	10.35	10.30	10.20	10.08	9.994	9.939	9.900	9.876	9.859	9.842	12.934	365.0	.00
80	Not Available																					9.846	13.728	351.5	14.53
81	12.30	11.41	11.10	10.90	10.77	10.67	10.58	10.50	10.45	10.39	10.35	10.30	10.24	10.17	10.12	10.07	10.03	9.959	9.897	9.846	9.809	9.798	12.745	365.0	.00
82	12.59	11.82	11.43	11.21	11.08	10.98	10.89	10.77	10.66	10.55	10.43	10.31	10.18	10.09	10.04	10.01	9.989	9.948	9.925	9.897	9.851	9.843	13.099	365.0	.00
83	12.06	11.28	10.98	10.83	10.71	10.63	10.57	10.51	10.46	10.40	10.34	10.29	10.25	10.19	10.13	10.08	10.02	9.959	9.906	9.848	9.820	9.804	13.095	365.0	.00
84	12.52	11.60	11.15	10.89	10.71	10.57	10.47	10.36	10.24	10.17	10.11	10.02	9.966	9.919	9.882	9.857	9.847	9.831	9.812	9.788	9.750	9.739	13.088	366.0	.00
85	12.09	11.18	10.89	10.75	10.66	10.59	10.51	10.46	10.40	10.36	10.30	10.25	10.21	10.18	10.15	10.12	10.09	10.06	10.04	10.00	9.934	9.906	12.765	359.3	5.75
86	12.59	11.59	11.15	10.98	10.84	10.71	10.61	10.52	10.45	10.38	10.32	10.27	10.23	10.20	10.16	10.12	10.09	10.07	10.04	10.02	9.940	9.930	13.385	365.0	.00
87	Not Available																					9.907	12.834	337.0	28.01
88	13.01	12.08	11.51	11.18	10.97	10.78	10.65	10.54	10.45	10.39	10.33	10.30	10.27	10.23	10.21	10.18	10.15	10.12	10.09	10.06	10.01	9.995	13.944	366.0	.00
89	12.17	11.26	11.00	10.85	10.72	10.62	10.53	10.44	10.32	10.20	10.10	10.03	9.984	9.950	9.913	9.879	9.856	9.832	9.822	9.806	9.796	9.789	12.870	365.0	.00
90	12.63	11.88	11.39	10.93	10.67	10.51	10.38	10.30	10.21	10.14	10.09	10.04	9.995	9.949	9.892	9.871	9.846	9.820	9.806	9.792	9.774	9.769	13.542	365.0	.00
91	12.09	11.34	11.08	10.86	10.70	10.59	10.47	10.39	10.33	10.27	10.19	10.12	10.07	10.04	10.01	9.980	9.964	9.936	9.887	9.854	9.824	9.815	13.035	365.0	.00

ᴄᴄ	1%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	99%	Minimum Level	Maximum Level	Valid Days	Valid Years
x.	13.01	12.08	11.69	11.40	11.17	11.01	10.89	10.80	10.73	10.67	10.61	10.55	10.51	10.48	10.44	10.41	10.37	10.32	10.28	10.24	10.17	10.153	13.944		33
›tal	12.51	11.58	11.17	10.94	10.78	10.67	10.58	10.50	10.43	10.37	10.31	10.26	10.21	10.17	10.13	10.09	10.04	9.989	9.927	9.863	9.816	9.672	13.944	12047	33
n.	11.62	11.03	10.71	10.53	10.43	10.35	10.28	10.23	10.16	10.11	10.08	10.01	9.951	9.916	9.882	9.826	9.792	9.748	9.732	9.696	9.677	9.672	12.084		33

›TE: All Levels are in metres above .000 m.O.D.

Produced by the Hydrometric Section, OFFICE of PUBLIC WORKS

Table 5

FLOW DURATION CURVES m3/s 1802 Ballyduff, (Munster Blackwater Catchment) RIVER ----- Blackwater

Year	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	99%	Minimum Daily Mean	Yearly Mean Flow	Total Valid Days	Total Down Days
1956	138.6	99.24	78.34	71.75	66.10	60.95	56.22	53.10	50.17	44.67	41.82	39.33	37.50	35.74	30.66	24.83	21.07	18.62	16.94	16.01	15.210	56.00	366	0
1957	Not Available																				9.281	49.39	326	39
1958	171.4	132.3	111.7	100.0	91.27	83.05	76.78	72.04	67.28	62.79	59.13	55.71	52.64	49.68	46.62	43.07	38.24	33.50	28.27	20.62	20.498	75.59	365	0
1959	157.6	120.9	98.34	83.45	72.30	65.51	58.90	53.09	47.41	40.39	32.13	25.90	21.87	18.06	15.74	13.49	10.93	9.314	8.492	7.997	7.815	54.60	365	0
1960	206.7	169.0	147.6	122.4	108.7	91.34	82.90	75.62	69.21	64.36	55.70	51.67	46.74	40.99	34.87	28.99	24.39	21.44	18.73	16.15	15.756	80.51	366	0
1961	156.7	131.1	96.70	74.99	59.10	49.95	44.07	36.17	28.62	23.21	19.70	18.11	15.07	12.65	11.42	10.47	9.812	9.408	9.021	7.354	7.312	47.68	365	0
1962	123.3	95.09	77.77	68.27	60.60	53.26	47.66	42.47	37.39	32.33	26.26	21.88	19.82	18.78	17.80	16.91	16.06	15.30	14.59	13.65	13.570	45.93	365	0
1963	170.3	118.9	97.40	80.35	68.88	62.19	54.09	49.63	46.74	43.71	40.05	33.71	28.76	24.82	22.74	21.21	19.87	18.71	17.45	15.66	15.571	57.83	365	0
1964	157.6	109.3	84.67	67.04	57.67	52.67	48.77	45.46	42.75	40.32	37.27	33.17	29.36	26.42	24.00	21.93	19.88	18.75	17.58	15.92	14.844	53.85	366	0
-	191.1	136.8	108.7	89.98	74.77	62.89	56.03	51.34	48.04	45.32	42.37	39.45	36.27	30.87	26.80	24.02	21.55	19.66	18.19	16.26	15.771	64.15	365	0
,	196.4	153.7	129.9	112.2	92.32	74.68	65.67	56.23	50.88	46.21	38.68	31.62	27.14	23.09	20.37	18.38	16.77	15.12	13.43	11.65	11.104	66.31	365	0
1967	140.4	109.8	88.08	78.07	70.37	64.47	58.72	53.49	48.63	43.89	40.06	34.63	30.18	22.95	19.36	17.62	16.20	13.96	12.11	10.42	10.359	53.63	365	0
1968	166.4	109.9	83.42	69.69	65.93	61.01	53.36	47.80	42.10	35.82	30.71	24.93	21.20	19.46	18.25	17.26	16.42	15.34	13.75	12.64	12.353	52.79	366	0
1969	147.1	90.16	69.23	52.58	42.34	33.66	27.38	22.88	19.68	17.64	16.04	14.38	13.04	11.85	10.75	9.803	9.118	8.262	7.397	6.505	6.302	38.30	365	0
1970	176.8	116.8	94.75	75.86	60.57	51.24	44.11	37.58	30.23	26.61	22.14	19.83	18.77	17.74	16.12	14.65	13.41	11.38	11.38	11.38	11.317	48.73	365	0
1971	99.68	75.95	60.54	53.43	46.30	42.40	39.58	34.33	30.34	26.95	22.44	19.07	17.71	16.65	15.66	14.77	13.98	13.35	12.76	12.04	11.970	37.26	365	0
1972	188.8	142.0	115.3	102.3	91.99	81.28	72.12	66.98	62.45	55.80	48.76	43.61	39.66	36.79	33.76	29.91	25.51	21.88	19.06	17.50	17.399	70.74	366	0
1973	145.4	114.4	100.8	90.21	81.53	74.24	68.29	63.36	57.65	53.79	50.66	48.19	45.94	43.58	41.04	38.41	35.73	33.23	30.05	24.13	21.263	66.36	365	0
1974	230.4	154.4	118.2	95.19	80.78	69.62	63.78	56.96	50.02	43.82	39.66	36.20	30.52	26.15	22.86	19.50	15.97	14.08	12.52	10.70	10.641	67.14	365	0
1975	140.4	92.02	76.39	67.54	60.76	53.97	45.75	38.52	33.66	30.25	27.38	24.45	21.29	16.19	12.51	10.68	8.764	8.267	7.173	7.173	7.131	44.96	365	0
1976	122.8	90.74	78.24	71.09	66.34	61.08	50.87	45.34	38.75	34.55	28.44	22.49	18.99	16.15	13.57	11.24	9.434	8.182	6.767	6.020	5.986	44.91	366	0
1977	163.9	139.1	124.5	111.1	101.4	91.85	84.41	76.44	64.16	49.76	38.13	29.43	20.17	16.27	14.74	13.41	12.21	11.29	10.45	9.047	8.383	64.27	365	0
1978	176.8	124.2	109.0	100.9	91.07	82.31	72.58	63.10	43.96	33.50	25.85	20.14	18.07	16.82	15.77	15.02	14.31	13.16	11.37	8.819	8.769	60.81	365	0
1979	153.4	129.1	113.9	103.6	94.52	86.85	80.78	75.14	70.08	66.21	62.27	57.05	49.96	38.96	27.91	22.02	17.48	15.27	13.64	12.63	11.944	69.95	365	0
1980	Not Available																				12.148	70.60	351	15
1981	150.2	122.9	106.8	93.91	85.36	78.07	72.79	67.87	63.28	56.07	50.48	45.21	36.80	31.21	27.11	23.14	18.26	14.75	11.93	10.16	9.789	63.92	365	0
1982	185.1	160.9	134.9	123.3	114.4	105.2	95.16	85.11	76.14	64.94	52.20	36.52	28.43	24.84	22.91	20.50	18.01	16.48	14.54	11.96	11.887	76.08	365	0
1983	142.5	114.4	99.57	89.64	83.42	77.72	72.29	67.46	62.99	55.63	48.99	43.90	39.29	33.09	27.31	23.32	19.14	14.96	12.36	10.10	10.038	61.81	365	0
1984	172.6	130.5	105.0	87.21	77.40	69.29	57.79	45.19	36.27	30.10	23.40	18.81	16.09	14.02	12.53	11.82	11.13	10.40	9.226	7.303	7.261	54.06	366	0
1985	132.0	105.4	93.01	85.61	79.51	72.70	67.91	64.02	57.56	50.31	44.55	40.18	37.03	34.10	31.27	28.58	26.54	24.50	21.53	16.82	15.632	60.44	359	6
1986	165.8	127.6	112.4	100.6	88.49	79.66	67.71	60.84	54.01	46.95	39.91	35.70	32.42	28.10	25.16	22.95	21.01	19.32	17.88	12.90	12.828	64.55	365	0
1987	Not Available																				11.700	52.15	335	30
1988	220.8	169.8	130.0	112.0	94.80	82.84	71.36	61.77	53.20	47.01	42.60	39.07	35.50	32.73	30.07	27.63	25.63	22.94	20.48	16.77	16.670	74.92	366	0
1989	138.7	113.1	100.2	90.16	79.84	72.17	60.68	44.67	32.55	24.88	18.52	15.43	13.53	12.01	10.36	9.107	8.308	7.670	7.116	6.641	6.602	48.80	365	0
1990	193.9	151.2	112.8	84.14	71.75	60.19	50.24	37.05	31.25	26.79	23.10	19.78	16.75	13.58	12.09	10.92	9.819	9.213	8.475	7.699	7.654	55.18	365	0
1991	152.9	120.1	104.4	89.86	78.07	68.35	59.71	52.65	43.85	35.26	29.34	25.51	23.24	20.76	19.03	17.78	15.92	13.11	11.46	9.769	9.713	54.71	365	0

Record	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	99%	Minimum	Mean	Days	Years
Max.	230.4	169.8	147.6	123.3	114.4	105.2	95.16	85.11	76.14	66.21	62.27	57.05	52.64	49.68	46.62	43.07	38.24	33.50	30.05	24.13	21.263			33
Total	165.4	125.3	104.2	88.96	78.09	69.26	62.38	54.67	48.61	42.92	37.62	32.46	27.59	23.46	20.11	17.87	15.63	13.16	10.45	7.657	5.986	58.69	12047	33
Min.	99.68	75.95	60.54	52.58	42.34	33.66	27.38	22.88	19.68	17.64	16.04	14.38	13.04	11.85	10.36	9.107	8.308	7.670	6.767	6.020	5.986			33

Table 6

Produced by the Hydrometric Section, OFFICE of PUBLIC WORKS

Duration Curves

There are three types of duration analyses .....

(a) Stage Duration Curves and (b) Flow Duration Curves

Due to seasonal variation these should only be calculated from years with complete records otherwise a bias will result. Duration Curves are produced for each valid year of data and an average Duration Curve for the period is evaluated (Tables 5, 6). These Curves allow the determination of the percentage of time, (based on the number of days over the period of record), that a given Level or Flow was exceeded. This indicates the Exceedance probability of a given water level or discharge. The derivative of the curve at the magnitude under consideration gives the Probability Density Function.

(c) D-Day Duration Curves

These indicate the probability of occurrence of discharge for a stated duration in days. The entire requested range of complete years is treated as a single group and Flow Duration Curves are produced for 1-day, 3-day, 7-day, 10-day, 15-day and 30-day moving average flows. For each given "D-days" the Table of D-day exceedance values are estimated for a selection of exceedance percentages (Table 7).

General Note on Developing and Plotting Flow Duration Curves

The accuracy of these Flow analyses is greatly improved by using Logarithmic Class Intervals instead of Linear Intervals of the Discharge range because Logarithms expand the number range for small numbers and reducing it for large numbers, this makes the analysis more sensitive to changes in low flows. There is also an improvement in the clarity of interpretation and a reduction in the curvature of the Flow Duration Curves when the Flow Logarithms are plotted against percentage exceedance.

The Institute of Hydrology, Wallingford, Oxon, ("Low Flow Studies, Report No. 2.1", 1980), suggest that the discharge interval's lower bound should be plotted against the Exceedence Probability on Log-Normal graph paper. To allow plotting on linear graph paper, they propose the use of an approximation to the Normal Variate, (X-plot); this is plotted against $Log_{10}(Q)$. P is the exceedence probability expressed as a fraction; when P is less than 0.5 then X-Plot is negative.

X-plot= 1.238T(1.0+0.0262T), where $T= [-Ln(4P(1.0-P)]^{0.5}$

1802 Ballyduff, (Munster Blackwater Catchment)

D-Day Percentage Exceedence values using data from 1956 to 1991

Exceedence Percentage	1-Day Q%1	3-Day Q%3	7-Day Q%7	10-Day Q%10	15-Day Q%15	30-Day Q%30 (m3/s)
5.00	163.076	159.114	152.147	148.258	143.066	134.506
10.00	124.296	124.374	123.560	122.339	119.884	114.825
25.00	77.871	79.820	81.551	82.398	83.148	83.258
33.33	64.643	65.682	67.445	68.295	69.067	69.937
50.00	43.702	44.919	46.506	47.651	48.854	50.780
66.67	26.379	27.291	28.805	29.565	30.771	34.357
75.00	20.183	20.739	21.679	22.254	23.216	25.877
90.00	13.342	13.518	13.838	14.055	14.491	15.117
95.00	10.665	10.768	10.989	11.139	11.432	12.223
99.00	7.745	7.808	7.874	8.014	8.182	8.485
Min. Average	5.986	6.045	6.097	6.127	6.214	6.642 (m3/s)
Total Number	13149	13149	13149	13149	13149	13149 (Days)
Sample Total	13059	13049	13029	13014	12989	12924 (Days)
Difference	90	100	120	135	160	225 (Days)

Produced by the Hydrometric Section, OFFICE of PUBLIC WORKS

D-Day is a term used for the Duration in days, e.g. 10-Day is of 10 days duration. A D-Day average discharge is developed from consecutive D-Days of river flow, e.g. Q 10-Day is the average discharge (m3/s) flowing for a duration of 10 days, which equals the total amount of water that flowed for the 10 days in question.

'Exceedence Percentage' is the Percentage of time that a given Discharge was exceeded. Thus, the average discharge over 10 consecutive days of flow which was exceeded by 95% of the estimates will be found on the 6st. Row '95' and in the 4th. Column 'Q%10'. This Q95%,10-Day is commonly referred to as Q95,10. Also, the minimum 10 day flow is found in the 'Min. Average' Row and '10-Day' column.

'Total Number' lists the maximum number of possible D-Day discharges that can be produced in the given record length, where each D-Day average starts at midnight, 24 hours after the previous average.
'Sample Total' gives the number of samples developed from the Data, these may differ from the numbers in the 'Total Number' Row due to breaks in the Hydrometric record.
'Difference' gives the difference in the above Totals.

Table 7

1611 Clonmel (Suir Catchment)

Calendar Years 1968 to 1992 No. of valid years= 25

The Annual Minimums, (in increasing order), are ....

5.518	6.373	6.755	7.049	7.414	7.485	7.569	7.817	8.131	8.132
8.279	8.375	8.481	8.995	9.277	9.309	9.439	9.571	9.790	10.795
11.212	12.751	12.967	13.310	15.980					

Standardised Minimums: Q/Qbar

.5978	.6904	.7318	.7636	.8031	.8108	.8199	.8468	.8808	.8809
.8969	.9073	.9188	.9744	1.0050	1.0084	1.0226	1.0368	1.0606	1.1695
1.2146	1.3814	1.4047	1.4419	1.7312					

Plotting Positions: E(y), (for the EV1 distribution)

-1.29	-1.00	-.81	-.65	-.52	-.40	-.28	-.17	-.06	.05
.16	.27	.38	.50	.62	.75	.89	1.04	1.21	1.40
1.63	1.90	2.25	2.78	3.80					

Q bar = 9.2309 (m3/s)

Least Squares estimates Q(T)= 8.0891 - 1.97540Ln(Ln(Tam))
Moments estimates ...... Q(T)= 8.1284 - 1.91008Ln(Ln(Tam))
Maximum Likelihood estimates Q(T)= 8.1598 - 1.80236Ln(Ln(Tam))

Annual Minimum Return Period Flows, (m3/s)

Using the Least Squares estimates

T	2	3	5	10	25	50
Q(T)	8.813	7.903	7.149	6.442	5.780	5.395

Using the Moments estimates

T	2	3	5	10	25	50
Q(T)	8.828	7.949	7.219	6.535	5.895	5.523

Using the Maximum Likelihood estimates

T	2	3	5	10	25	50
Q(T)	8.820	7.990	7.302	6.657	6.053	5.701

Table 8

1101	Boleany (Owenavorragh Catchment)					RIVER -----	Owenavorragh				Minimum Daily Mean	Yearly Mean Flow	No. Estd. Flows
Year	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%			
1974	53.14	38.64	25.39	13.12	5.117	.288					.811	3.69	0
1975	111.9	83.13	55.55	33.35	14.63	2.278					.743	2.52	0
1976	86.46	61.55	39.39	18.54	4.866	1.029					.726	3.07	0
1977	71.68	48.52	28.52	11.01	1.037						.919	4.29	0
1978	83.92	53.07	29.33	15.43	3.473	.0389					.854	3.21	0
1979	29.39	13.58	5.347	1.953	.142						1.036	4.01	0
1980	30.29	16.02	7.231	5.088	3.053	1.469	.397				.580	4.31	12
1981	22.67	12.73	4.868	1.450							1.071	4.04	0
1982	32.67	20.03	8.338	3.469	.442						1.002	4.29	0
1983	29.09	13.12	3.894	1.025							1.127	3.39	1
1984	117.8	90.51	64.39	40.20	17.95	4.145	.0059				.708	3.04	0
1985	31.66	18.36	8.527	2.056	.123						1.006	3.56	0
1986	4.650	.738	.0139								1.414	3.88	0
1987	45.76	26.36	13.67	5.320	1.879	.801	.178				.600	3.60	12
1988	6.103	2.749	.447								1.337	3.98	0
1989	99.21	75.29	51.67	29.33	10.27	.658					.813	2.87	0
1990	120.2	90.83	63.75	38.33	18.88	5.780	.0671				.695	2.99	0
1991	72.18	48.37	25.50	8.910	1.140						.943	3.40	0

Using the 18 Valid Years of Data from 1974 to 1991 the Estimated Long Term Mean Flow is 3.57 m3/s

Produced by the Hydrometric Section, OFFICE of PUBLIC WORKS

Ey(i)	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%
-1.19	4.650	.738	.0139							
-.87	6.103	2.749	.447							
-.65	22.67	12.73	3.894	1.025						
-.47	29.09	13.12	4.868	1.450						
-.30	29.39	13.58	5.347	1.953	.123					
-.15	30.29	16.02	7.231	2.056	.142					
.00	31.66	18.36	8.338	3.469	.442					
.15	32.67	20.03	8.527	5.088	1.037					
.30	45.76	26.36	13.67	5.320	1.140					
.46	53.14	38.64	25.39	8.910	1.879	.0389				
.63	71.68	48.37	25.50	11.01	3.053	.288				
.82	72.18	48.52	28.52	13.12	3.473	.658				
1.02	83.92	53.07	29.33	15.43	4.866	.801				
1.26	86.46	61.55	39.39	18.54	5.117	1.029				
1.54	99.21	75.29	51.67	29.33	10.27	1.469	.0059			
1.91	111.9	83.13	55.55	33.35	14.63	2.278	.0671			
2.44	117.8	90.51	63.75	38.33	17.95	4.145	.178			
3.47	120.2	90.83	64.39	40.20	18.88	5.780	.397			

Produced by the Hydrometric Section, OFFICE of PUBLIC WORKS

(assuming an Extreme Value Type 1 distribution)

1101 Boleany (Owenavorragh Catchment) RIVER ----- Owenavorragh Long Term Mean Flow= 3.57m3/s

25% Demand Level = .893 (m3/s)

			T=	2	3	5	10	25	50
Least Squares	Q(T)=	-1.133 -	1.9692Ln(-Ln(1-1/T))=		.645	1.821	3.298	5.166	6.551
Moments estimates	Q(T)=	.961 -	1.5087Ln(-Ln(1-1/T))=	1.514	2.323	3.224	4.356	5.786	6.848
			SE(Q(T))=	.593	.753	.998	1.347	1.816	2.173

20% Demand Level = .714 (m3/s)

			T=	2	3	5	10	25	50
Least Squares	Q(T)=	-.317 -	.2049Ln(-Ln(1-1/T))=				.144	.338	.482
Moments estimates	Q(T)=	.085 -	.1341Ln(-Ln(1-1/T))=	.134	.206	.286	.387	.514	.608
			SE(Q(T))=	.0791	.100	.133	.180	.242	.290

Produced by the Hydrometric Section, OFFICE of PUBLIC WORKS

Table 9

Cumulative Discharge or The Mass Curve

This is a simple cumulative distribution of a year's discharge. Due to the seasonal nature of the Hydrological Cycle, this analysis requires complete years.

Low Flow Analyses

These are extreme value Statistics and as such, can be analysed by one of the Extreme Value distributions. In Ireland it has been found that they are reasonably well fitted by the Extreme Value Type 1 , (EV1) or Gumbel distribution. The Tables of the estimates for return periods of 1, 2, 3, 5, 10, 25 and 50 years are produced for the following three analyses ....

(a) Annual Minimum

These are the Series of Annual Minimum flows and estimates of the return period Annual Minimum Daily Flows are produced (Table 8).

(b) Sustained low Flow

Sustained Low Flows are defined as the lowest mean flow estimates which were not exceeded for the given duration, (in days). For example, the 7-Day S.L.F. for a given year is found by getting the smallest 7-Day moving average, i.e. the driest week's average flow; the largest Daily Mean Flow in that 7 days period is the S.L.F. for the Year. From this definition it is evident that the 1-Day S.L.F. is the minimum D.M.F. for the year. Plotting each of the ranked series of D-Day S.L.F.s indicates their relation to the ranked series of Annual Minimums. This statistic is very useful in Fishery investigations and in the granting of effluent and abstraction licences.

The Sustained Low Flows are developed for each available year and the overall record for the durations of 1-Day, 3-Day, 7-Day, 10-Day, 15-Day and 30-Day.

(c) Reservoir Storage

This analysis results in the production of a table giving the minimum amount of storage necessary to maintain the Flow of water, (past the gauging station), at a specified set of percentages of the long term mean flow, (Table 9).

High Flow Analyses

These anaylses use the Hydrometric year or Flood year which starts on the 1st. of October and finishes on the following 30th of September, the two high flow analyses in general use are ....

(a) Annual Maximum Analysis

This is an extreme value analysis which uses the series of the highest instantaneous peak discharge from each valid Hydrometric year with the Extreme Value Type 1 or Gumbel Distribution which has been found to produce a satisfactory fit for Irish data.

(b) Partial Duration Analysis

This is not an extreme type analysis, it uses all the flood peaks greater than a given value which is generaly chosen to allow, on average, two peaks per year to be accepted. The difficulty with this analysis is in having to distinguish between independant and dependant peaks, eventhough there are rules they are not completely satisfactory. The Exponential distribution produces a good fit for Irish data.

Problems in Interpreting and Accepting the Standard Analyses

When imperical proceedures are applied to data such as in the development of Flow Duration Curves the results are subject to error, this may be due to the inaccuracies in the original data because of poor measurement and evaluation or it may be due to the record being small. This can be seen when the Flow Duration Curve based on one year's data is plotted with the Mean Duration Curve for a period of twenty years.

Imperical results do not generaly plot in a regular, smooth fashion, if you assume regularity then this is an extra assumption and it can reduce the accuracy of any interpretations based on the smooth curve.

It is assumed a piori that a probability Distribution exists to describe a given statistic such as the Annual Minimum Series. For many of the statistical methods that are used in Hydrology the only physical basis for choosing a specific probability distribution as a model is that the data plot on a straight line. This is always the first thing that must be checked. If the data does not fall on a straight line then ....

First, the data must be checked for any possible error.

Second, if no data error exists a new interpretation must be advanced which explains why the record behaves as it does. This interpretation must be based on the physical conditions and/or hydrology of the catchment. For example, when the Annual Maximum series at 2503 Annacotty on the Mulkear is plotted the result is not a straight line as would be expected from experience, the data fall on two connected lines, the line of the lower peaks rises quickly while the upper line which starts at about the 5 year flood has very poor growth. There is a clear physical reason why this is so, much of the river upstream was subject to an old embankment scheme which is not succesful in containing the larger floods. Once one of these tops the embankment it spills out over a very large area and its peak discharge is greatly reduced, hence the small differences in the big floods at Annacotty. Statistically it can be said that these larger floods do not belong to the same parent population of floods as the smaller ones and they should be treated seperately. Third, if there is no explanation for the problem then the analysis must be rejected for that station's record.

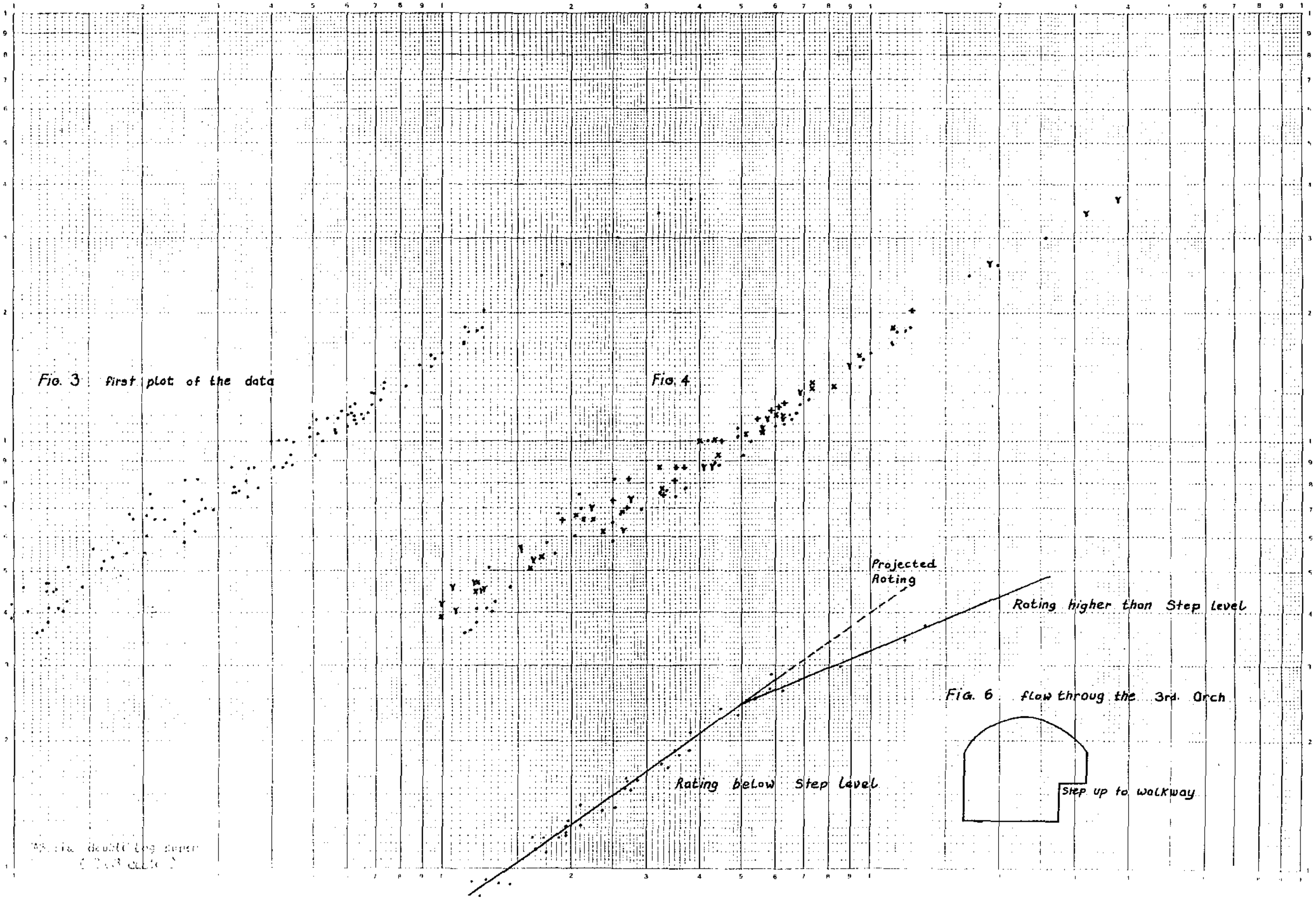


Fig. 3 first plot of the data
Fig. 4
Projected Rating
Rating higher than Step level
Rating below Step level
Fig. 6 flow throug the 3rd. Orch
Step up to walkway

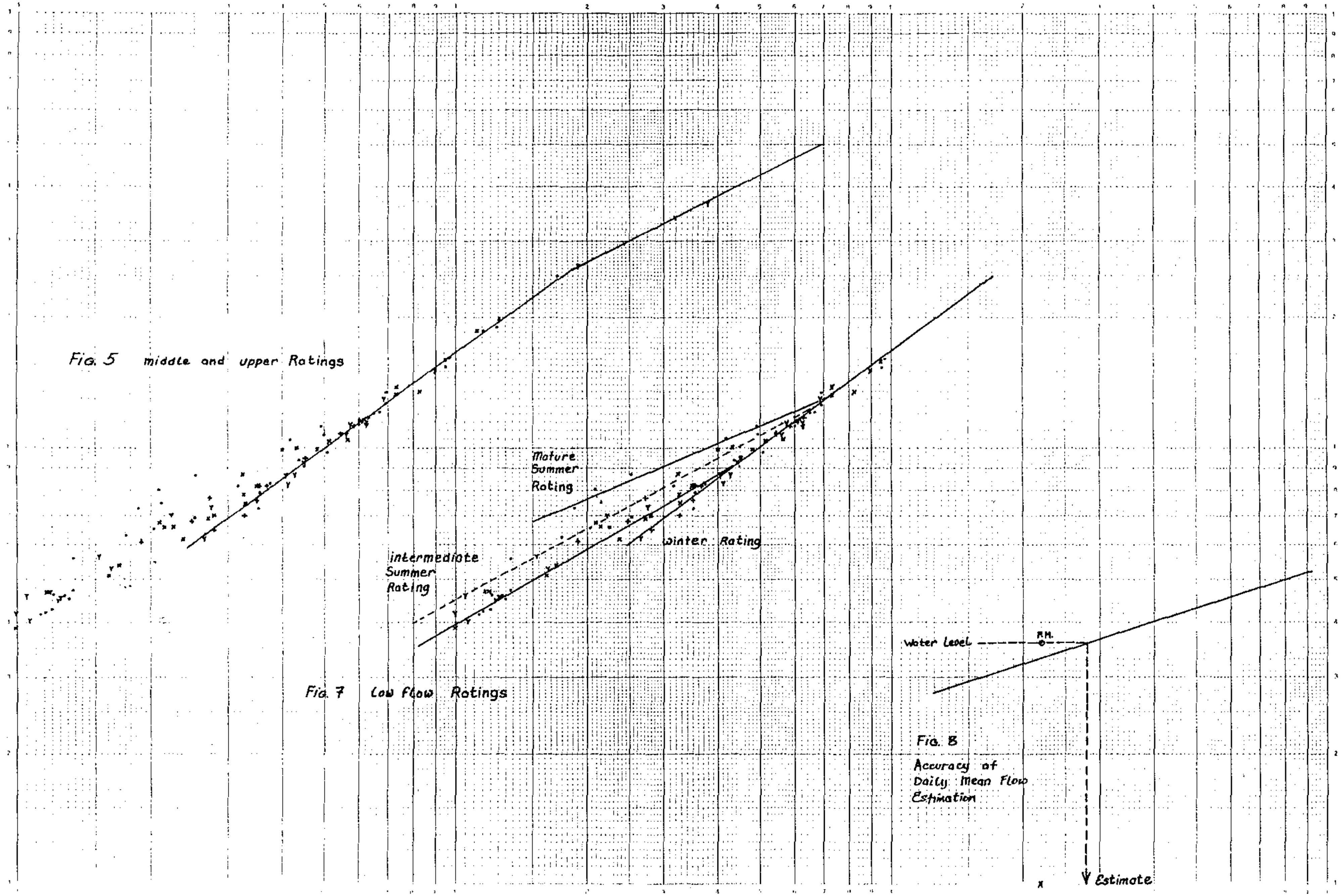


Fig. 5 middle and upper Ratings
Mature Summer Rating
intermediate Summer Rating
winter Rating
Fig. 7 Low flow Ratings
Water Level
R.H.
Estimate
Fig. 8
Accuracy of Daily Mean Flow Estimation

20/IV/'93

FIRST DRAFT

River Flow modelling - An introduction.

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Abstract

In the context of rainfall - runoff transformation of daily data, the principle of following a systematic procedure of model development, rather than expressing a commitment to any one model, is discussed and illustrated with two examples.

The essence of this principle is 'progressive modification' of the model (Nash and Sutcliffe, 1970) from the simple towards the more complex only when sufficient improvement, as expressed by a significantly better fit, justifies the additional complexity.

Introduction

Operational river flow forecasting models are used as components in flood forecasting schemes where flood forecasts are required to issue warnings and to permit the evacuation of populations. Very often river flow in the upper catchment is estimated from the average rainfall in the catchment and the flows of many such streams are combined and routed down the main channel. Such models are also used for reservoir regulation and occasionally for stream flow synthesis.

In recent years, operational forecasting models, have been used to asess the impact of possible climatic change on the Water Resources of a region. The predicted changes in rainfall, temperature and humidity etc., based on the outputs of General Circulation Models, can be transformed into riverflow with the help of river flow forecasting models.

Physically distributed forecasting models can be used to asess the impacts of human activities on a watershed. For example, deforestation and irrigation, could be represented directly by changes in model parameter values and the models could be used to predict the hydrological effects of such changes. However, the development of such models based, purely, on the laws of physics are still in its early stages of development and have not yet provided an alternative to the traditional empirical models.

Operational river flow forecasting models can be generally classified into two types; the *Systems type* and the *Conceptual type*.

The systems approach depends on the prior assumption of a very general, flexible, relationship (eg. linear and time invariant), the expression of which may be obtained by the application of the systems analysis methods to the records. Some examples of models in this category are the Simple Linear Model (SLM) (Nash and Foley,), the Linear Perturbation Model (LPM) (Nash and Barsi,), the Seasonally Varying Runoff Coefficient model (SVRC) (Kachroo et al, 1992), the Constrained Linear Systems Model (CLS) (Natale and Todini,), the Multi Linear Model (MLM) (Kachroo and Natale,), the Linearly Varying Gainfactor Model (LVGM) (Ahsan and O'Connor, 1993) and the Volteirra Series Model (VSM) (Amorocho,). SLM is a linear time invariant model. LPM and SVRC are seasonal models. The remaining are non linear models.

The conceptual models, on the other hand, represent the transformation of rainfall and potential evaporation (input) into runoff (output) by a model which consists of a series of steps representing in a very simplified manner the known physical processes of the hydrological cycle. These models are non linear and the input data are usually simplified by replacing spatially variable functions by their areal means. Examples of this category are the Sacramento Model ( ), the SSARR model ( ), the NAM Model ( ),the Xinanjiang model ( ), the Layers Model ( ) and so on.

The selection of an appropriate model, amongst a large choice of available models, should not be a matter of choosing any one model but to develop a model that is suitable for the catchment and the purpose for which it is being developed.

The principle of following a systematic procedure of model development has always been the policy of University College Galway. This policy was followed in a series of International Workshops held at University College Galway since 1985 where data from a large number of catchments from various geographical and climatic regions of the world were analysed.

The essence of this philosophy is the procedure of 'Progressive modification' of the model (Nash and Sutcliffe, 1970) from the simple towards the more complex only when sufficient improvement, as expressed by a significantly better fit, justifies the additional complexity.

Systematic model development comprises a three step iterative procedure.

Step 1:

Assume a simple model structure

While it is desirable that a model should represent as closely as possible the actual physical processes occuring within the catchment, it is essential that it should represent accurately the transformation of the input into the output. The usefulness of the model is reflected in the extent to which it satisfies this primary objective, which may be defined as 'model accuracy'. The second requirement is that of 'consistency' whereby the level of accuracy and the estimates of the parameter values persist through different samples of the data.

Since the available data for operational models is usually averaged over large catchment areas it becomes difficult to optimise a large number of parameters with this data. To maintain consistancy it is ,therefore, essential that the model should have a small number of parameters so that each parameter has an effective function.

Therefore the first step in the model development process is to assume a simple model structure but one which can be easily modified.

The Simple Linear Model (described later) is the most suitable starting model form. It can be handled elegantly with the Linear Algebra and it can be very easily modified. It will be shown, later in the paper, that most of the non linear and time variant (seasonal) models of systems type are modified forms of the Simple Linear Model.

Step 2

Optimise its parameters and check their stability.

There is an array of methods which can be used to estimate the response function of Simple Linear Model. These can be classified into non parametric methods and parametric. The non parametric methods include ordinary least squares, Ridge regression, constrained least squares and quadratic programming. The parametric methods depend on formulating the Linear model in a small number of parameters (like representing the response function by a gamma function) and then optimising the parameters by non linear search techniques like the Rosenbrock, genetic alogrithm or the Simplex method.

Since most of the non linear systems type models are modifications of the Simple Linear Model, therefore, the methods of parameter estimation are the same as that of the Simple Linear Model.

These methods will not be discussed in this paper because the emphasis of the paper is on model formulation rather than on parameter estimation.

A common test to check the consistancy or the stability of the parameters is to divide the available data into two parts one for the model calibration and the other for model verification. The accuracy of the model fit should persist through the verification period if the estimated parameters are stable.

Step 3

Apply diagnostic checks to the residuals.

The model residuals carry information that can provide indications of the inadequacy in the model structure and also suggest the direction of desirable modification.

There are three different tests that are usually applied.

(a) Test for seasonality
(b) Test for Functional relationships
(c) Test for persistance.

Tests (a) and (b) will be described later with the help of examples but the third test (c) will not be discussed in this paper because if this test is found positive then the model must be changed from a 'simulation type model' to an 'updating type model'. This distinction and category of models will not be discuused in this paper.

Efficiency Criteria

The most commonly used objective function is the sum of squares of differences between the observed and the estimated discharge.

Based on this criteria Nash and Sutcliffe (1970) defined the model efficiency R^2 as the proportion of the initial variance accounted for by the model.

$$R^2 = 1 - \frac{F}{F_o} \quad \text{Where} \quad F = \sum (y - \hat{y})^2$$

$$\text{and} \quad F_o = \sum (y - \bar{y})^2$$

The initial variance is calculated in the calibration period by subtracting the mean of the calibration period from the observed data of the calibration period. In the verification period it is calculated by subtracting the mean of the calibration (not verification) period from the observed data of the verification period.

This definition is a general indicator of the model accuracy but it must be interpretted with caution when the mean of the observed discharge in the calibration is significantly different from the mean of the verification period (Kachroo and Natale, 1992). However, in this paper it will be the only criteria that will be used.

The Data

The use of the procedure of 'progressive modification' is demonstrated with the help of results obtained on two catchments; the catchment of Sanaga and that of the Bird Creek. Sanaga is a large catchment of 131500 Sq. Kms in Cameroon. It is of mixed topography with grass land and Forest. Bird Creek is a small catchment of 2344 sq. Kms with rolling terrain and 80% grass land.

Both the catchments are of rainfall - runoff type. Daily averaged (spatially averaged) rainfall and daily discharge data was used for the purpose of developing the systems type models. For conceptual type models potential evaporation was also used but only for the CAtchment of Bird Creek.

The length of the available data was 8 years. Out of which 6 years were used for calibration and the remaining 2 years for verification.

The Simple Linear Model and the results of its application.

Simple Linear Model described by the following equation

$$y_i = G \cdot \sum_{j=1}^{m} z_j \, x_{i-j+1} + e_i$$

is the simplest representation of a causal, time-invariant, relationship between an input function of time (x) and the corresponding output function (y). The pulse response function is given by (z) where m is its assumed memory. The gainfactor (G) is the ratio of the total output to the total input. The sum of the ordinates of Z are unity.

The pulse response function of this model can be estimated by ordinary least squares but this estimate is not generally satisfactory because the resulting response function can have negative ordinates caused by numerical instability.

There are other methods of estimating the response function Z under the constraints of volume and shape but the one used in this work was to represent the pulse response function Z by the gamma function impulse response and to replace G by the ratio of the observed sum of outflow to the observed sum of inflow. The two parameters of the gamma function (n and nk) were estimated by Rosenbrock's optimisation method.

The results of the application of the Simple Linear Model (SLM) to two catchments under consideration are given in Table 1. It's comparison with the seasonal model forecast is given in Table 2.

Seasonal model forecast is a smoothed date averaged mean of the observed discharge data.

Figure 1 is a comparison of the smoothed seasonal mean discharge calculated from the observed data and the one calculated from the estimated discharge of the Simple Linear Model for the catchment of Sanaga.

Figure 2 is a distribution graph of the residual variance after fitting Simple Linear Model to the catchment of Bird Creek.

Table 1

Summary of the Results obtained with a simple Linear Model (SLM).

Catchment	Model Efficiency(%) Calibration	Model Efficiency(%) Verification
Sanaga	70	66
Bird Creek	60	-53

Table 2

Comparison of the results obtained with the Simple Linear Model (SLM) and the Seasonal Model.

Catchment	Model Efficiency(%) SLM/Seasonal Calibration	Model Efficiency(%) SLM/Seasonal Verification
Sanaga	70/91	66/86
Bird Creek	60/4	-53/-35

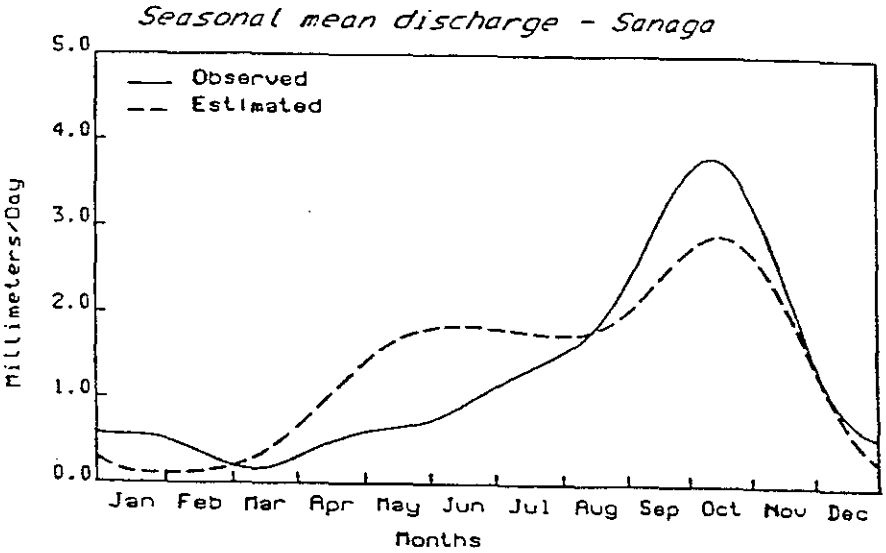

Figure 1: Observed and estimated (SLM) Seasonal Mean discharges for Sanaga.

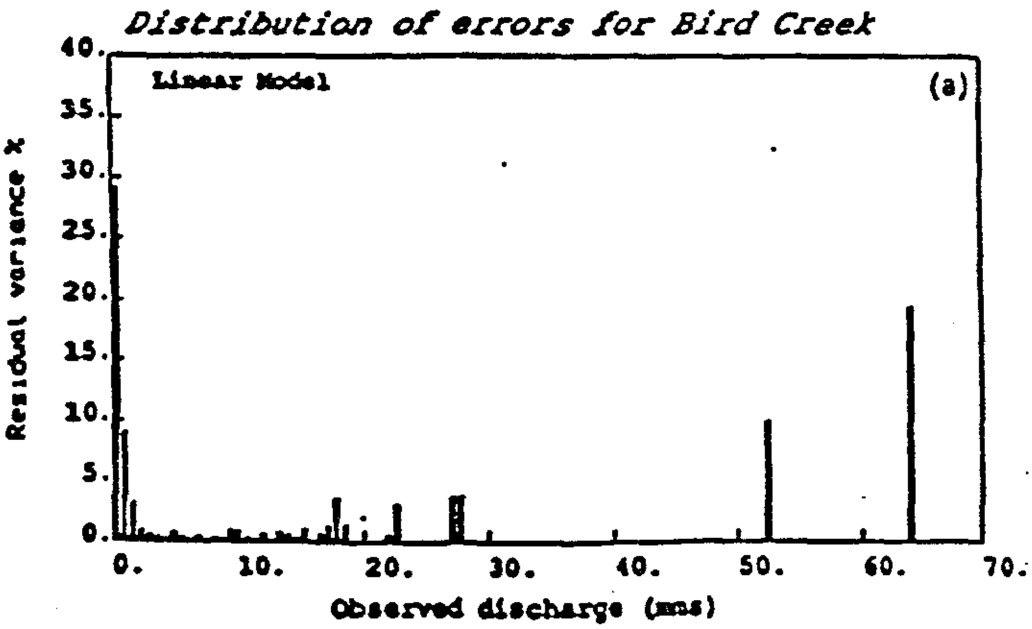

Figure 2: Distribution of the residual variance after fitting SLM for Bird Creek

Tables 1 and 2 and figures 1 and 2 clearly indicate that the two catchments are very different in their runoff generation characteristics and will hence require different types of modifications to the assumed model. The efficiency of the Seasonal model, which is simply a date averaged mean function, is higher than the Simple Linear Model in the case of Sanaga. Figure 1 clearly indicates that the seasonal effect is very pronounced in the case of Sanaga. The Simple Linear model consistently underestimates in the high flow season and overestimates the flow in the other seasons. Therefore, importance of incorporating seasonal effect in 'the Sanaga model' is vital.

On the other hand, Bird Creek is not a seasonal catchment. The Seasonal average is more or less the same as the ordinary average. From figure 2, it can be seen clearly that the Simple Linear model has failed to perform satisfactorily in the extreme high and low flows.

Therefore, the Simple Linear Model must be modified to incorporate the requirements of the two catchments, either in a single modified form or in two different forms.

The Linear Perturbation Model and the results of its application.

The well pronounced effect in the Sanaga Catchment can be easily incorporated in the Linear Perturbation Model, which is described by the following equation.

$$Q_i = \sum_{j=1}^{m} R_{i-j+1} h_j + e_i \qquad i = 1, 2, \ldots, n.$$

Where

$$Q_i = y_i - y_d$$

$$R_i = x_i - x_d. \qquad d = 1, 2, \ldots, 365.$$

It assumes that R, the perturbations or departures from the smoothed seasonal input values (xd) are linearly related to Q, the corresponding perturbations or departures from the seasonal model forecasts,i.e., from the smoothed seasonal output values (Yd).

The results of its application to the catchments under consideration are presented in Table 3. From these results it can be concluded that a model which incorporates seasonal effects ,such as a Linear Perturbation model, is suitable for large and humid catchments like Sanaga. For Bird Creek, the model shows no improvement over the results of the Simple Linear Model.

Table 3

Comparison of the results obtained with the Simple Linear Model (SLM) and the Seasonal Model (SM) and the Linear Perturbation Model (LPM)

Catchment	Model Efficiency(%) SLM/SM/LPM Calibration	Verification
Sanaga	70/91/96	66/86/90
Bird Creek	60/4/60	-53/-35/-44

The Multi Linear Model and the results of its application.

The non linear effect exhibited by the catchment of Bird Creek (figure 2) can be incorporated by assuming a model which has different linear relationships for different magnitudes of flow like the MultiLinear Model or the Constrained Linear Systems Model. The effect can also be incorporated in the Linearly Varying Gainfactor model or the 2nd Order Volterra Series Model.

The results of the four models are not expected to vary significantly for each other because each one of them essentially incorporates the same effect which is higher response to high intensity rainfall and a lower response to low intensity rainfall.

The results of the application of Multi Linear Model are presented in Table 4.

Table 4

Comparison of the results obtained with the Simple Linear Model and the Multi Linear model.

Catchment	Model Efficiency(%) SLM/MLM Calibration	Model Efficiency(%) SLM/MLM Verification
Bird Creek	60/??	-44/??

Soil Moisture Accounting and Routing Model and the results of its application.

Coneptual models permit the grouping together of the non linear operations, i.e., the manner in which rainfall and evaporation interact to produce runoff, and leaves open the possibility of representing the subsequent transformation of these generated runoff components of rainfall by a linear routing component. One such model is the Soil Moisture Accounting and Routing Model (SMAR). This is a 2 parameter version of the originally proposed model by O'Connell et al. (1970) known as layers model.

The model assumes that the catchment is an infinitely large tank comprising of layers of 25 mms each. Part of the rainfall becomes runoff. The proportion is controlled by a parameter H.

The evaporation takes place at potential rate from the first layer. From the 2nd layer evaporation takes place at C times the potential rate. From the 3rd layer it is C sqaure times the potential rate and so on.

Runoff is created only at the sturation of the tank. The quick and the delayed runoff is lumped together and routed through a linear routing component.

This is a very simple model with 2 parameters in the Water Balance component and another 2 parameters in the routing component. The parameters of this model were calibrated by Rosenbrock optimisation procedure.

The results of the application of this model to the catchment of Bird Creek has shown significant improvement in foreacst efficiency compared to the LPM (table 5).

Table 5

Comparison of the results obtained with the Simple Linear Model and the SMAR model.

Catchment	Model Efficiency(%) SLM/SMAR	
	Calibration	Verification
Bird Creek	60/88	-44/72

Conclusions:

Operational models of flood forecasting can be classified as systems type or the conceptual type. The *choice* of an appropriate model is not a question of choosing a model from a variety of available models but to develop a model suitable for the catchment and the purpose for which the model is being used.

The essence of this philosophy is the procedure of 'Progressive modification' of the model (Nash and

Sutcliffe, 1970) from the simple towards the more complex only when sufficient improvement, as expressed by a significantly better fit, justifies the additional complexity.

From brief analysis of two catchments, Sanaga and Bird Creek, it was found that models which incorporate seasonal effects like the Linear Perturbation Model can give good results on large humid catchments like Sanaga. On small catchments, like the Bird Creek, the choice of models is between non linear systems models like the Multi Linear Model or conceptual models like the Soil Moisture Accounting and Routing Model.

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Hydrogeology
of the
Dolomite Aquifer
in the
Southeast of Ireland

E.P Daly
Groundwater Section
Geological Survey

A complete copy of the lecture presented to the 13th Annual IAH (Irish Group) Seminar on Basin Management and Information Technology, held at Portlaoise on 20-21th of April 1993. The notes highlighted and copies of overheads are additional to the meeting proceedings.

Groundwater Report - Summary Sheet

Report Number: GW 93/5 Author(s): E. DALY

Report Title: Hydrogeology of the Dolomite Aquifer in the Southeast of Ireland Date Completed: May 1993

Status:- Open File [/] Confidential [ ] Read but not copy [ ]

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Area Concerned:

National: Yes [ ] No [ ]

Regional: Yes [/] No [ ] Which region: Southeast

River Catchment(s): mainly the Barrow, Nore and Suir

County(s): ____

Local area: ____

6" Sheet No.: ____ 25,000 Sheet(s): ____

Principal Groundwater Topics Covered: Hydrogeology, Dolomites and Dolomitisation.

Geological Succession Covered: middle Dinantian

Objectives in Writing Report: Compilation of a lecture given to the IAH in Portlaoise.

Other remarks: ____

Introduction

The dolomitised limestones of the southeastern part of Ireland are one of the most important bedrock aquifers in the country. They are found within the area bounded by Southwest Dublin, Portlaoise, Thurles, Cahir, Clonmel, Waterford and Rosslare. The aquifer has been developed as a source of supply for a number of water schemes in this area, eg. in Portlaoise, Athy, South Wexford, Carlow and Bagenalstown.

The relatively recent discovery of four zinc-lead orebodies in the aquifer, two of which are deemed to be commercial, has added to it's importance and the need to fully understand its hydrogeology. Detailed hydrogeological investigations have been carried out in the Nore River Basin area, in those areas where the aquifer has been developed for water supply and more recently around the orebodies at Galmoy and Lisheen.

Dolomite is one of the major aquifer types throughout the world and it is widely distributed, eg. in the American Mid-West, Italy, Spain and South Africa. In some places the dolomite is also associated with mineral deposits in others it is the reservoir rock for hydrocarbons.

Overhead 1 shows the extent of the regionally dolomitised limestones in the southeast. In late Chadian-Arundian times (Hitzman et al., 1992) show that carbonate deposition in this region occurred in shallow water. The so called Rathdowney Trend where major mineralisation occurs is located along the western edge of this dolomitised area.

There are other areas in Ireland where the limestones have been dolomitised. However they are much more localised presumeably because the dolomitisation is mainly hydrothermal in origin.

Geology

Dolomite($CaMg\{CO_3\}_2$) is a mineral usually found with carbonate rocks although it does not form as a sediment. The dolomite mineral frequently replaces the calcite and aragonite minerals($CaCO_3$) which form naturally in a marine environment and are the dominant minerals in limestones. This process is called dolomitisation. The term Dolomite is reserved for rocks that contain in excess of 90% of the mineral dolomite. From a hydrogeological point of view the most important feature of dolomitisation is that it results in an increase in the porosity and permeability of a sediment as the crystal lattice of dolomite occupies about 13% less space than that of calcite(Freeze and Cherry, 1979).

The method of replacement of calcite in limestones by dolomite is one of the enigmas of geology. The most recent model for the formation of dolomite reported in Fowles (1991) suggests that hypersaline solutions, rich in magnesium, slowly circulating through permeable sediments in carbonate platforms result in the replacement of calcite. This process can be active from the early to late stages in the compaction (diagenesis) of the sediments.

Overhead 2. The mechanisms for the circulation are unclear at present. One possible cause is a density difference between warm waters within the pores and colder sea water or saline groundwater. Dolomites are thought to be forming at present at depth in parts of Florida and the Bahamas and in Bonaire Island (Netherlands Antilles). There appear to be similarities in the genesis of the Edwards Formation(Southeast Texas) and the dolomites of the Southeast of Ireland.

In the southeastern part of Ireland there has been extensive dolomitisation of the limestones particularly those strata in the middle of the Dinantian succession ie. in the Upper Ballysteen, Waulsortian(and equivalent), Crosspatrick and Aghmacart Formations(**Overhead** 3 and 4). The extent of the succession dolomitised is quite variable although there does appear to be a general decrease from east to west. The intensity of dolomitisation generally appears to be greatest in the originally cleaner (permeable Waulsortian and Crosspatrick Formations) strata and also along faults(**Overhead 5. The dolomitisation is seen to crosscut the stratigraphy. There is extensive dolomitisation along parts of the major fault that extends from Kilkenny to Waterford Cities.** In the eastern part of the area the finer and more argilaceous Ballysteen and Aghamacart Formations(normally aquitards) are also partially dolomitised(**Overhead 6 shows an horizon of dolomitised limestones within the Ballysteen Formation. The dolomitised horizons are seperated by undolomitised sections**). The thickness of the aquifer varies from a few tens of metres to a few hundred.

In the investigations carried out, at Bennettsbridge (Olsen, 1969) and Galmoy(Doyle et al., 1992) in Co. Kilkenny and at Kedrah (Jones and Fitzsimons, 1992) and Lisheen(Hitzman et al., 1992) in Co. Tipperary, it has been found that the alteration of the original strata has been complex and resulted from a number of geological processes that were sequential but also partially overlapping(**Overhead 7. All of the processes listed here do not occur throughout the area of concern in the southeast. These processes all tend to open up the rock. As the dolomite replaced the calcite the porosity increased allowing more magnesium rich fluids into the rock, and so on. The more intensly dolomitised the rock the greater the number of features that add to the K and S).** In general these processes have led to a coarser, more porous, brittle and locally intensively altered rock. **It has been found that dolomites formed soon after deposition tend to be fine-grained whereas recrystallation in late diagenitic dolomites produces a coarser-grained rock and an increase in porosity.** Over the extended area the regional dolomitisation, jointing/faulting and later weathering are the most important processes from a hydrogeological viewpoint.

In outcrop these rocks are very varied as befits their variable and complex origin. They frequently have a mottled(salt and pepper) or irregularly textured appearence. They range in colour from white or cream, to light grey or black and to buff where weathered. They are fine to coarse grained and porous or crystalline. They are severly jointed(N-S and E-W), friable, weathered and in places have been reduced almost to the consistency of a sand(Doyle et al. 1992 stated that it is most likely that oxidation took place during the Tertiary but may also be continuing to the present). In core these strata are typified by vugs which frequently exhibit good crystal growth, sand filled or solution(open) cavities, shrinkage cracks, veins and fractures.

Over the greater part of this area the dolomitised strata have been folded into a large broad syncline(Southeast Carboniferous Basin, Sheridan 1977) of Hercynian age and predominantly Caledonoid (NE-SW) trend. There are a number of smaller secondary anticlines and synclines associated with it. Overhead 8. It is likely that there are just as many faults in the southern half of this section. They await discovery. These rocks have been extensively faulted. There are a number of very large faults and also numerous smaller ones. The trend varies from NW-N-NE-ENE in direction.

In the south of the area the aquifer has been folded into a tight syncline with Hercynoid (E-W) trend. The rocks are traversed by a series of N-S faults.

Hydrogeology

These strata were originally thought to have little potential as aquifers mainly due to the difficulty of successfully completing boreholes through them. In the mid-1970's the true potential of this aquifer was initially detected by geological mapping, well drilling and baseflow analysis of the River Nore. It was subsequently confirmed by the discovery of the large springs through which the aquifer discharges in the Callan-Bennettsbridge Lowlands of Co. Kilkenny and by the completion of successful water supply schemes at Portlaoise and South Wexford.

This aquifer generally crops out in the relatively low lying ground of the limestone lowlands in the southeast. Hence the water table is generally less than 10m below surface with an annual fluctuation of less than 5m.

Small karst features such as caves, a turlough, highly permeable zones, swallow holes and surface solution are found in parts of this aquifer.

Porosity, Permeability and Well Yield

Dolomitisation is essential to the development of porosity and permeability in these strata. In this area there are numerous instances of undolomitised rocks with low permeability in close proximity to the same rocks(but dolomitised) with high permeability. Only the Crosspatrick Formation has significant and consistent permeability in the absence of dolomitisation. The dolomitisation of generally clean limestones increases their porosity and renders them susceptible to jointing, possibly faulting and subsequent karstification and weathering. The processes which control the development of porosity and permeability in these strata are largely unpredictable. Likewise for the distribution of the range of permeability and storage values.

The porosity and permeability of these rocks has been found to be greatest in intensly dolomitised areas, along wide fault\ fracture zones, within 30m of the surface and at particularly permeable horizons at depth(eg. in the Urlingford-Mountrath Lowlands the top of the Waulsortian is extensively dolomitised and hence should be very permeable). Overhead 9 The undolomitised rock is likely to have a K value of the order of 10^{-2}m/d and the faults/permeable horizons a value 20m/d. . Dolomitisation is not a near surface phenomenon and hence permeability can be anticipated to occur at depth. Permeability and weathering have been shown to exist at depths of over 100m (100m at Killamery(SE. Tipperary) and 125m at Lisheen(Hitzman *et al.* 1992) and significant shows of water were detected in a borehole at over 600m. Core samples from particular horizons give porosity values of 5% down to 10m and over 2% at depths from 30-300m.

In the more permeable parts of this aquifer well yields normally range from 500-2,000m^3/d with specific capacities of 50-200m^3/d/m. Transmissivity varies from 50-500m^2/d and the permeability from 0.5-10m/d. The storage coefficient is of the order of 10^{-3}-10^{-4}. In certain limited areas the aquifer has been shown to be more productive. Overhead 10. The values reported here are from pumping tests many of which were not ideal, did not always include observation wells and in which the abstraction wells generally only partially penetrated the aquifer.

Hydraulic Regime and Groundwater Flow

In a large aquifer such as this the hydraulic conditions are quite variable. In outcrop areas the aquifer is normally unconfined except for relatively small areas where it is confined by till. It is also confined by the large bog which extends to the north, west and south of Urlingford Co. Kilkenny. The aquifer is in continuity with the thick sands and gravels in the Barrow Valley. The aquifer is in hydraulic continuity with the overlying Crosspatrick Formation where it is undolomitised and considered to be a minor aquifer in it's own right.

The bulk of groundwater movement in these areas occurs relatively rapidly, at shallow depths, along short flow paths(Daly, 1989) and discharges, frequently via small springs, into the normally effluent streams which traverse the aquifer.

The boundaries of this aquifer are difficult to delineate owing to the variability of the dolomitising process which is central to the development of permeability. They rarely coincide with lithological limits and the contacts are generally gradational. The aquifer's upper boundary may vary from the top of the Waulsortian(or equivalent) through the overlying Crosspatrick Formation(a minor aquifer in it's own right) to over a third the way up the Aghmacart Formation. The lower boundary may vary from about 30m below the top of the Waulsortian to over half way down the underlying Ballysteen Formation.

The aquifer is confined in the centre of the Southeast Carboniferous Basin beneath a considerable thickness of sediment. Overhead 11. In this aquifer as in most other aquifers in Ireland the bulk of groundwater flow occurs near the surface. Arcon(1992) show that over 75% of groundwater in the aquifer in the Galmoy area is near the surface(Layer 1). Aside from the large springs through which the aquifer discharges in the Callan-Bennettsbridge Lowlands, there is a certain amount of evidence to suggest there is a significant amount of groundwater flow in this deeply confined area(Overhead 12). If flow does occur at depth it is likely to be fault controlled. Faults occur regularly throughout this area, probably at least every 500-1,000m. The large faults have displacements of up to 200m whereas the smaller ones are offset by up to a few 10's of metres.

There is also likely to be some confined flow at depth in the Carrick Syncline in the south of the area. Here the mainly easterly flow is likely to be considerably affected by the numerous N-S faults which can be expected to provide a partial barrier to flow.

Hydrochemistry and Water Quality

Calcium/magnesium bicarbonate($Ca/Mg[HCO_3]_2$) type waters with dissolved solids normally less than 500mg/l are typical of groundwaters in this aquifer. They are similar to those in other limestones except for the magnesium content which normally ranges from 20-40mg/l and is about twice that of limestone waters. This results from the recharging waters ability to dissolve both calcium and magnesium togethor until saturation/equilibrium is reached. As a result the dolomite waters are harder(350-425mg/l[as $CaCO_3$]) and have an elevated Mg/Ca ratio(<0.3). Overhead 13.

In the deeper confined parts of most aquifers in Ireland the slower moving groundwaters evolve to sodium bicarbonate($NaHCO_3$) type waters. The presence of these type of waters indicate that ion exchange is taking place. It is generally accompanied by reducing conditions. This type of groundwater is expected to be present in the deeper confined parts of this aquifer.

The quality of groundwaters in this aquifer are generally good and of potable quality as indicated by the analyses of waters from large springs and high yielding wells. However in many locations the aquifer is vulnerable to pollution as the lowland recharge areas are frequently covered by thin permeable soils and subsoils.

Aquifer Development and Groundwater Resources.

Effective rainfall over the aquifer ranges from around 375-550mm/y. As much of the outcrop area is covered by reasonably permeable soils, recharge is likely to be moderately high, ie. 200-350mm/y.

The aquifer(in ten individual units) is estimated to cover a total area of over 550km^2 with resources in excess of 140Mm^3/y(90-100x10^{6}g/d). Only a small proportion of the available resources have been developed todate(<10%).

Development

Optimum well yields from the Dolomite Aquifer will be obtained from boreholes drilled into one of the many fault zones and penetrate at least 50-100m of the aquifer. Ideally boreholes should coller at a point about 30m above one of the highly permeable horizons in the aquifer. Drilling into this aquifer at depths of over 200m, at favourable locations, have a reasonable prospect of success.

Drilling Conditions

Drilling conditions in this aquifer can frequently be very poor owing to the friable, cavernous and weathered nature of the material. Certain intervals give very poor recovery from wireline drilling(In some boreholes sections the recovery has been as low as 2%) . On the other hand cable tool and down-the-hole hammer drilling produces very large quantities of cuttings(Overhead 14). Drilling muds or additives are frequently required to get penetration and long casing runs and grouting are necessary to stabilize the large caverns often created underground by the drilling and/or flushing medium.

Well screens, slotted casing or a significant period of development may sometimes be necessary to produce sediment free water.

Conclusion

Dolomitisation/faulting/weathering are essential to the development in these rocks. Permeability is irregular and unpredictable and ranges widely. The boundaries are irregular and difficult to delineate. The bulk of groundwater movement is in the near surface layer but there is likely to be some flow at depth.

The dolomitised limestones in the Southeast of Ireland are an extensive aquifer, contain large groundwater resources and make a substantial contribution to baseflow in rivers. They have been successfully developed at a number of locations and are capable of yielding large quantities of good quality groundwater.

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There is also additional relevent material in the following internal Geological Survey Reports.

1981 Nitrate Levels in the Aquifers of the Barrow River Valley.

1982 Groundwater Resources of the Southeast Industrial Development Region.

1982 The Proposed Use of the Dolomite Quarry at Bennettsbridge, Co. Kilkenny, as a Landfill Site

1992 Groundwater Resources of the Nore River Basin(Draft)

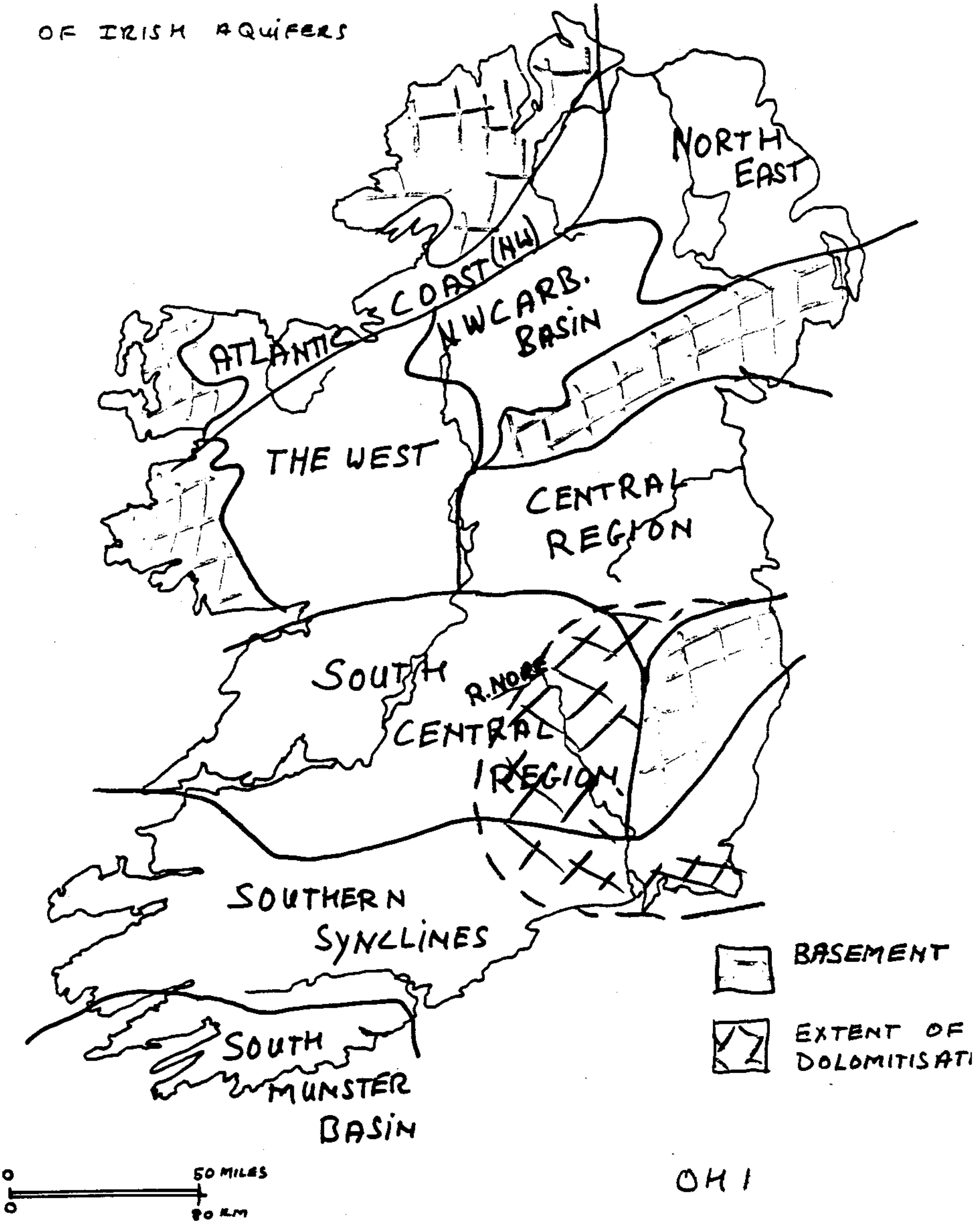
1993 A Conceptual Model for Irish Bedrock Aquifers.

APPENDIX 1

COPIES OF OVERHEADS USED IN THIS LECTURE

CONCEPTUAL MODEL

OF IRISH AQUIFERS



OH 1

Light grey limestone above, darker, porous dolomite below. The boundary follows bedding on the right, but cuts across on the left

ınly those with between 35 and 40 per cent sea water are ıitable. But perhaps the most important factor is that dolomite oes not precipitate in modern mixing zones. Mixed fluids re rarely saturated with respect to dolomite, so the mineral issolves if it is already there. Despite the initial enthusiasm, y the mid to late 1980s, many geologists felt that the Dorag ıodel was questionable, to say the least.

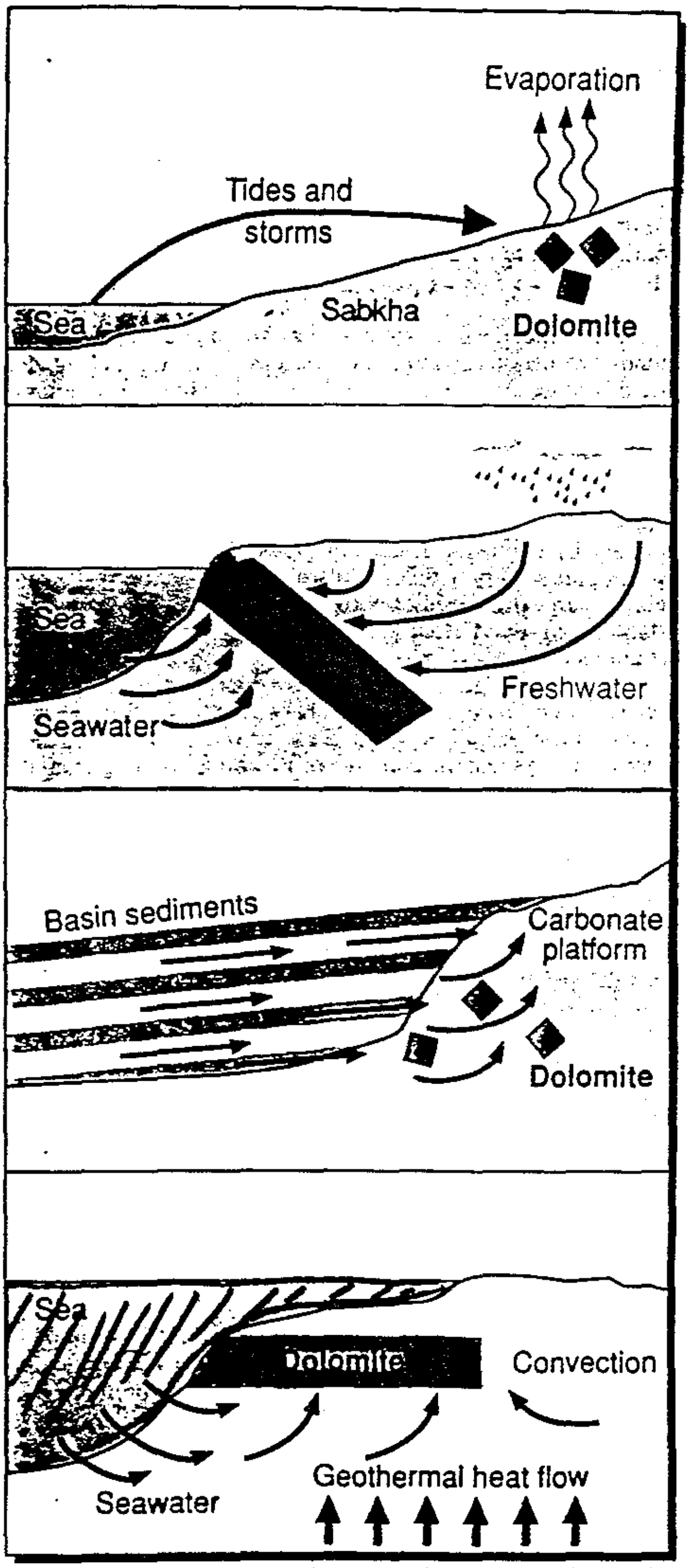
During the rise and fall of the Dorag model, experimental ·ork continued apace. In 1981, a paper was published which ·as to have far-reaching effects in the world of dolomite ıeories. Through the efforts of the Deep Sea Drilling Programme, dolomite had been discovered in sediments of the ɔntinental margins. Paul Baker and Miriam Kastner, of cripps Institution of Oceanography in San Diego, California, xperimented on the kinetic controls on dolomite precipitation ; part of a larger study of dolomite discovered in the drill ɔres. The experiments showed that sulphate in pore waters ıhibited the transformation of calcite at around 200 °C.

By extrapolating to lower temperatures, they concluded that ater with very little sulphate may provide conditions that are inetically favourable for the formation of dolomite. They ıggested that supratidal dolomites may form in this way, ecause the sulphate concentration of their pore fluids is reuced by precipitation of calcium sulphate and reduction of sulhates by bacteria. By implication, the reaction described in ıe Dorag model, then very much in favour, would also enınce dolomite growth by diluting the sulphate in sea water.

Baker and Kastner's results also stressed the importance of ctors other than the ratio of active magnesium to calcium. ıeir work showed that pore fluids with relatively low ratios, ıch as those found in continental margin sediments, could ·oduce dolomite. But like the Dorag model, the sulphate duction theory soon ran into problems. Once again it was ardie who summarised them.

The principal stumbling block is that, following the dis-ıvery of dolomite in the sabkha, small quantities of dolomite .ve been found in many modern environments. Often these .vironments have very high concentrations of sulphate, up to hundred times as much as the limiting values reported · Baker and Kastner. Hardie suggested that the sulphate ay simply retard the reaction rather than prevent it: over ɔusands or millions of years, the transformation could still ppen. With experiments lasting only two weeks, Baker and ıstner did not address this possibility. Today, sulphate duction is seen by many as something of a red herring, with ı important role to play in the dolomite debate.

During the 1980s yet another model took over. This invoked ıid from a different source, the compaction of shales in dimentary basins. Dolomite forms in the sediments at the



Model answers for dolomite formation: from the top, the sabkha model, in which sea water supplies the magnesium; the Dorag model, where sea water and ground water mix; burial of basin sediments may supply suitable fluids; and the latest idea brings the vital element from sea water circulating slowly underground

margin of the basin after they have been buried several kilometres deep, a proposal supported by the textures of many ancient dolostones, which formed after the rock had compacted and lithified. The burial model is attractive because many ancient dolostones are flanked by sediments that formed in basins. But like its predecessors, it has some serious problems.

OH2

FOWLES. NEW SCIENTIST 1991

DOYLE et AL 1992

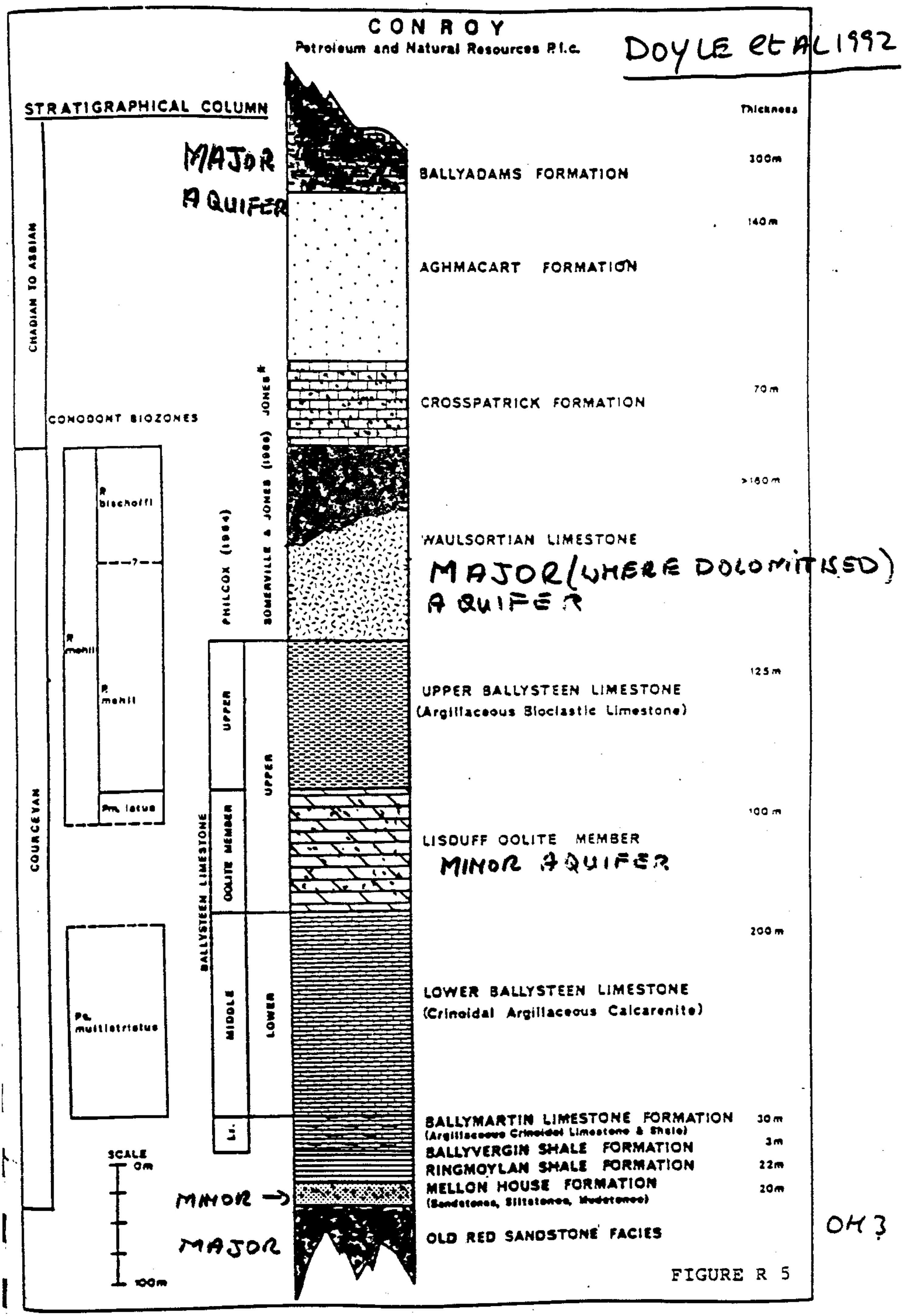
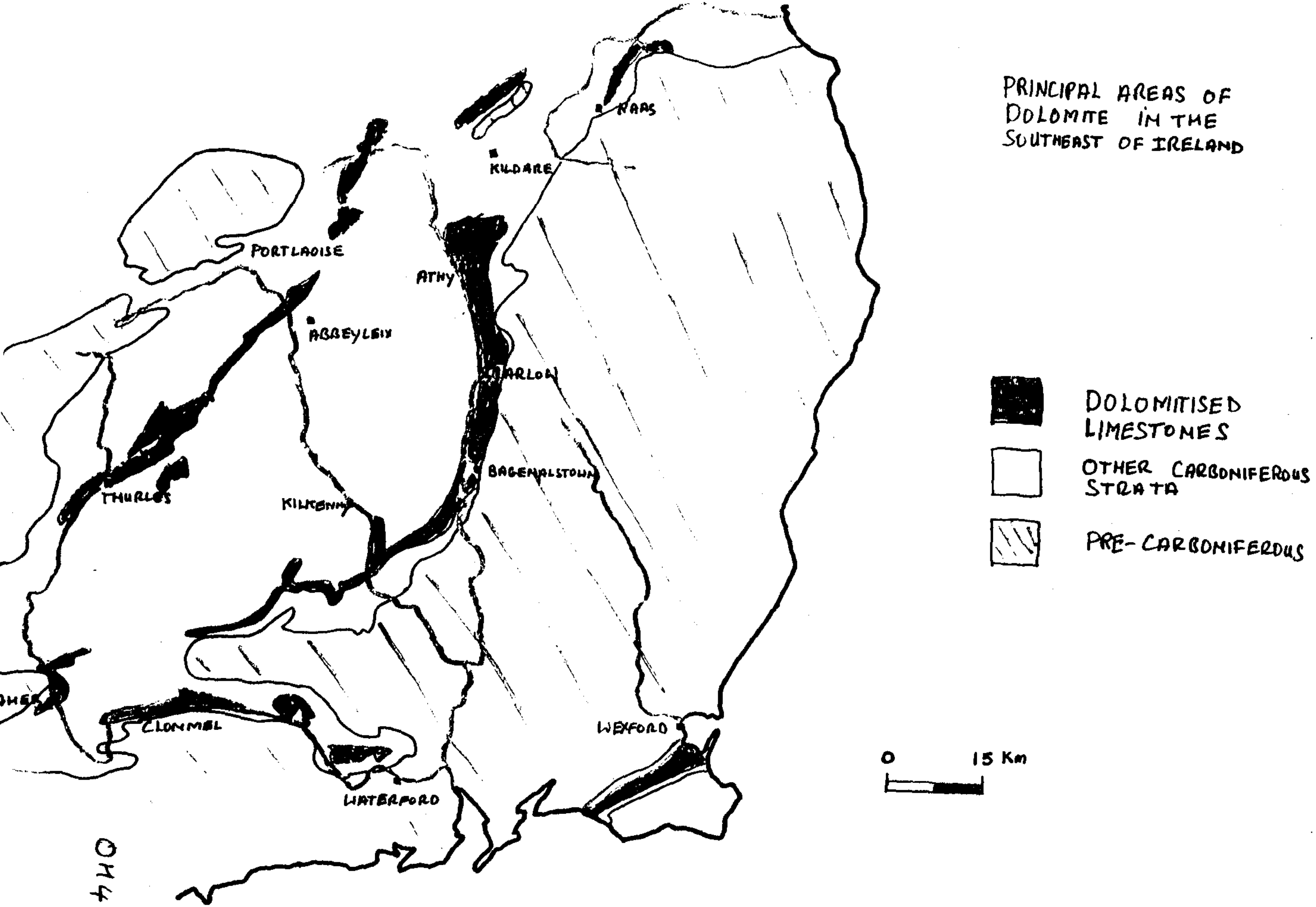
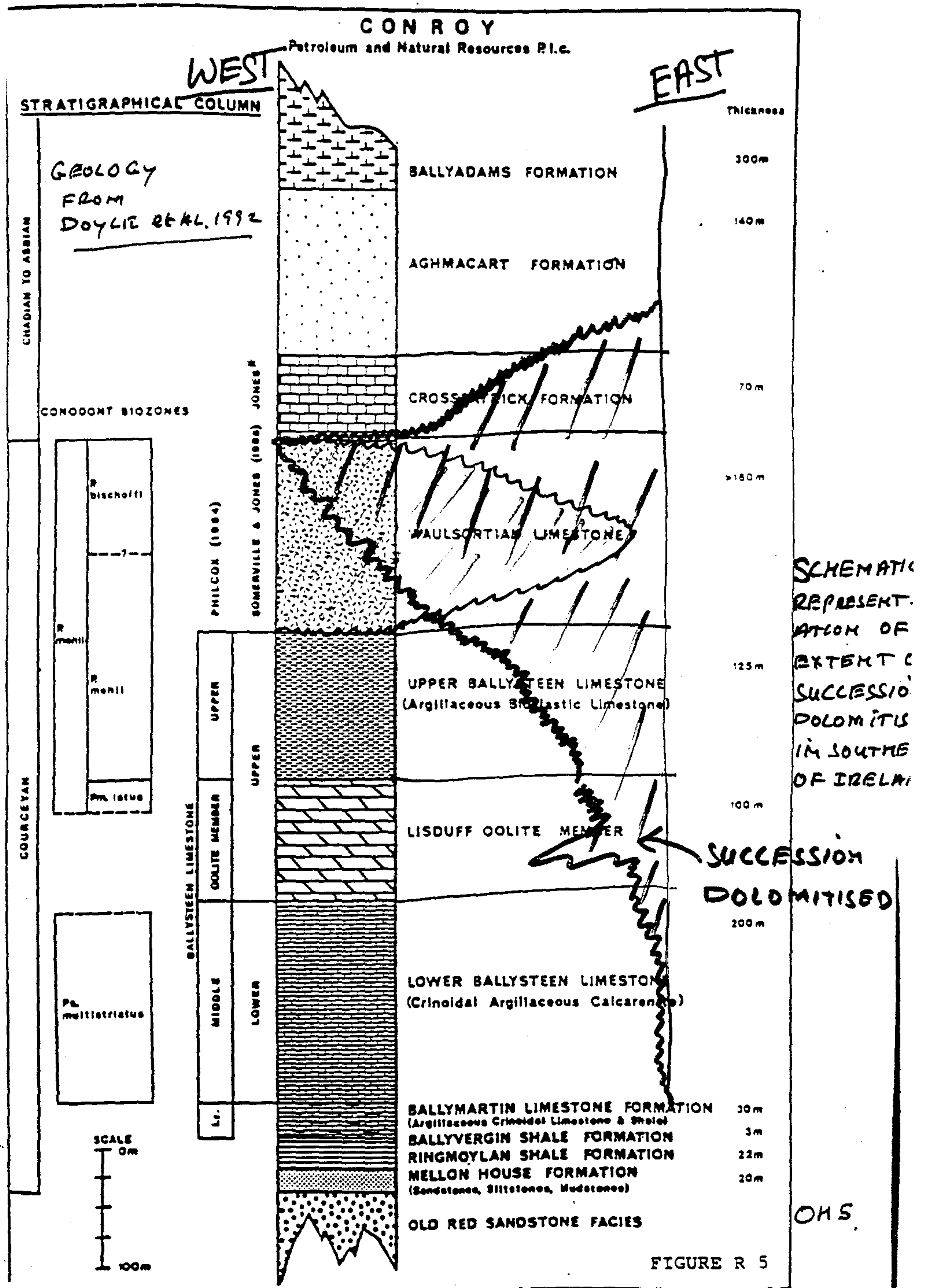


FIGURE R 5

OH 3


PRINCIPAL AREAS OF DOLOMITE IN THE SOUTHEAST OF IRELAND
DOLOMITISED LIMESTONES
OTHER CARBONIFEROUS STRATA
PRE-CARBONIFEROUS
0
15 Km
NAAS
KILDARE
PORTLAOISE
ATHY
ABBEYLEIX
CARLOW
BAGENALSTOWN
THURLES
KILKENNY
CLONMEL
WEXFORD
WATERFORD

OH4



CONROY
Petroleum and Natural Resources P.l.c.
WEST
EAST
STRATIGRAPHICAL COLUMN
GEOLOGY FROM DOYLE et AL. 1992
Thickness
CHADIAN TO ASBIAN
COURCEYAN
CONODONT BIOZONES
P. bischoffi
P. mehli
P. mehli
Pm. latus
Ps. multistriatus
PHILCOX (1984)
SOMERVILLE & JONES (1986) JONES*
BALLYSTEEN LIMESTONE
UPPER
OOLITE MEMBER
MIDDLE
UPPER
LOWER
Lr.
BALLYADAMS FORMATION
300m
140m
AGHMACART FORMATION
CROSSPATRICK FORMATION
70m
>160m
WAULSORTIAN LIMESTONE
UPPER BALLYSTEEN LIMESTONE
(Argillaceous Bioclastic Limestone)
125m
LISDUFF OOLITE MEMBER
100m
200m
LOWER BALLYSTEEN LIMESTONE
(Crinoidal Argillaceous Calcarenite)
BALLYMARTIN LIMESTONE FORMATION
(Argillaceous Crinoidal Limestone & Shale)
30m
BALLYVERGIN SHALE FORMATION
3m
RINGMOYLAN SHALE FORMATION
22m
MELLON HOUSE FORMATION
(Sandstones, Siltstones, Mudstones)
20m
OLD RED SANDSTONE FACIES
SCALE
0m
100m
SCHEMATIC REPRESENTATION OF EXTENT OF SUCCESSION DOLOMITISED IN SOUTH OF IRELAND
SUCCESSION DOLOMITISED
OHS

FIGURE R 5

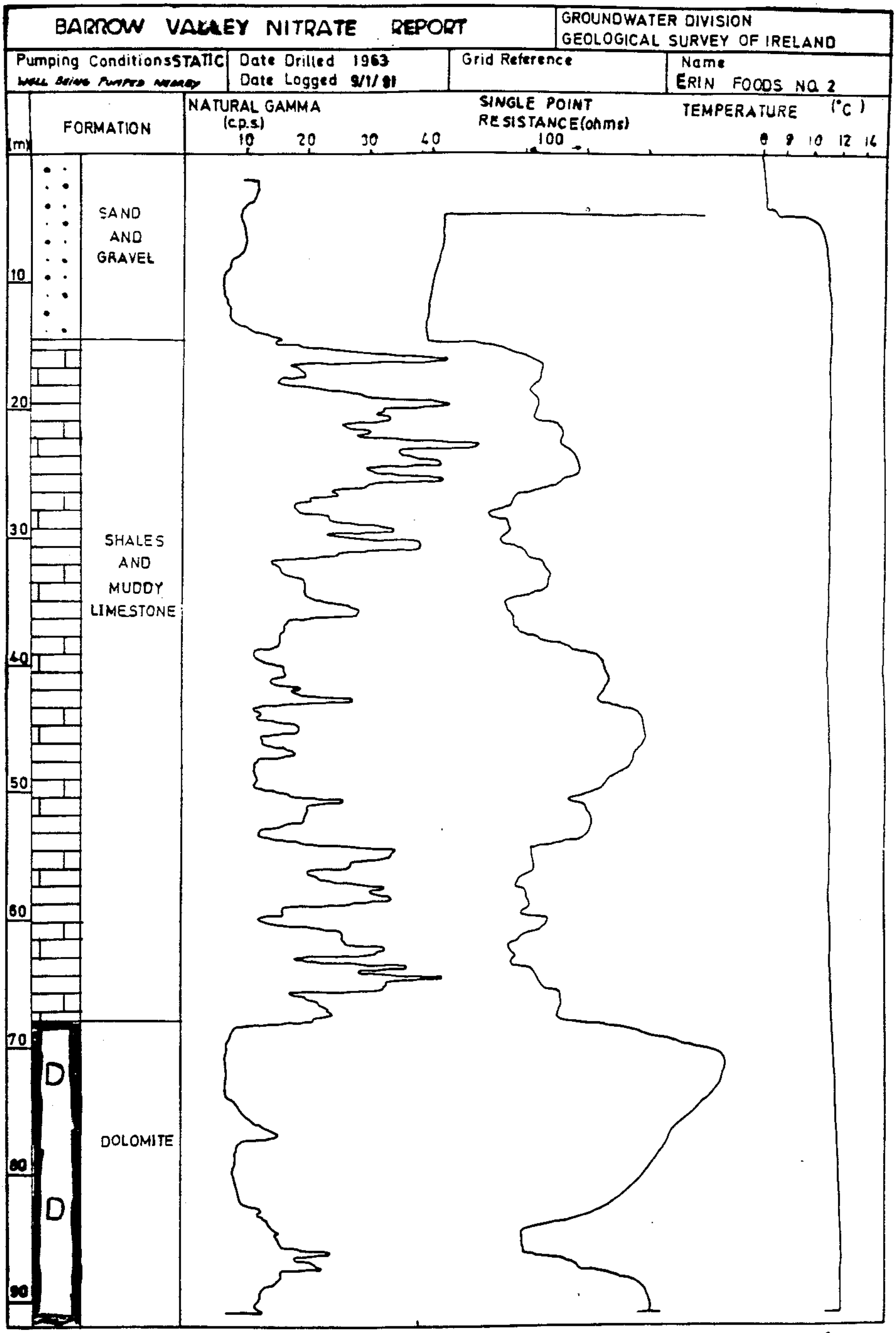


Figure4 Geophysical Well Logs of boreholeCW 7/2

OH6

(iv) Fine pyrite crystals, usually oxidized, within the dolomitized Waulsortian above the rock matrix breccia and the main mineralization: much of this pyrite predates the crystalline breccia although in places it is seen to be caught up in dolomite veins. Usually it appears to line the veinlets or brecciated stromatactis cavities.

may also, in part, be a separate phase. Much of the mineralization occurs as open space fill, either in a fine-vein network or stockwork, or in small vugs.

Mineralized intersections range between 3m and 30m, although in every case the holes, being

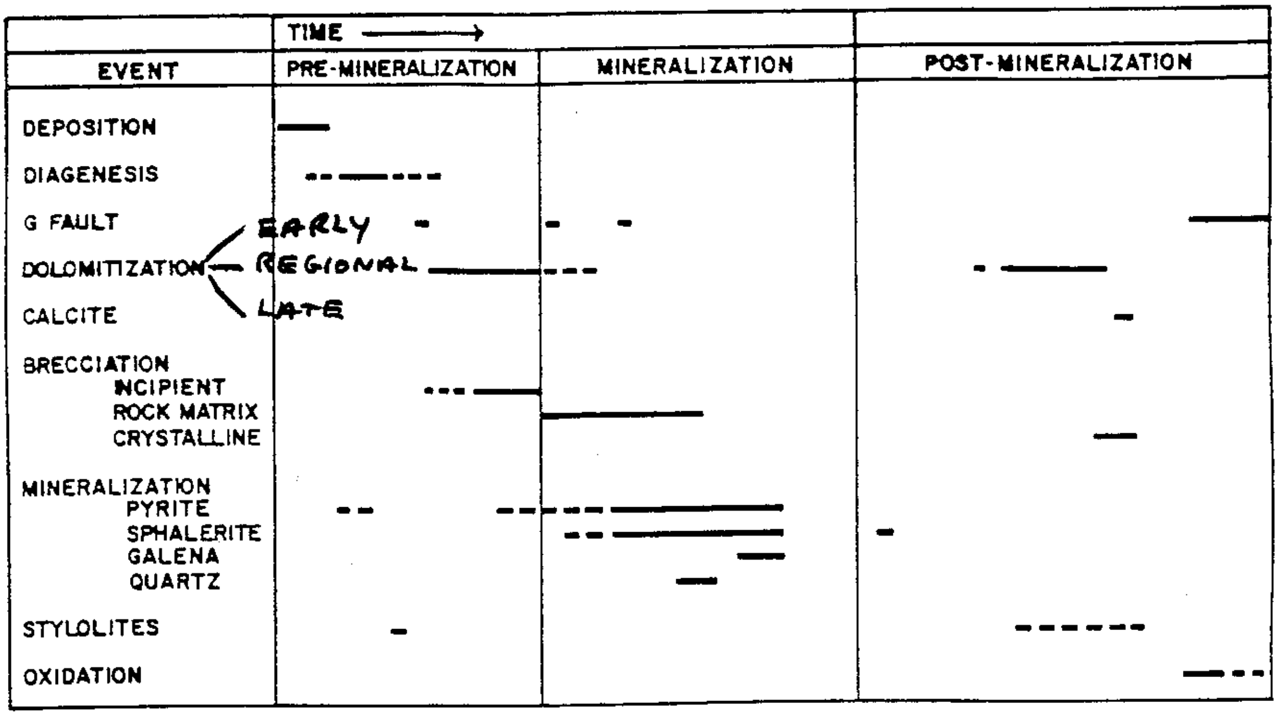


Figure 6. Sequence of events affecting the rocks at Galmoy.

Galena

Two textural varieties of galena are recognized:

(i) Fine-grained galena as fine disseminations enclosed within sphalerite.

(ii) Coarse intergrowths with sphalerite.

The second variety appears to have infilled voids. In rare instances galena occurs in veinlets cross-cutting other mineralization.

Copper-silver mineralization

Several holes drilled in the southern part of the G Orebody passed through the G Fault to intersect copper-silver mineralization with minor mineralization in dolomitized Lisduff Oolite Member and lower Ballysteen Limestone. This fracture-fill mineralization is epigenetic and is closely related both to the G Fault and to dolomitization. Chalcopyrite and tetrahedrite-tennantite are the main copper minerals. Higher silver values are associated with increasing concentrations of tetrahedrite-tennantite, but silver

vertical and intersecting an inclined zone, give an apparent thickness. The best intersection to date is 30m grading 2.08% Cu and 70g/t Ag including 10m grading 5.36% Cu and 185g/t Ag.

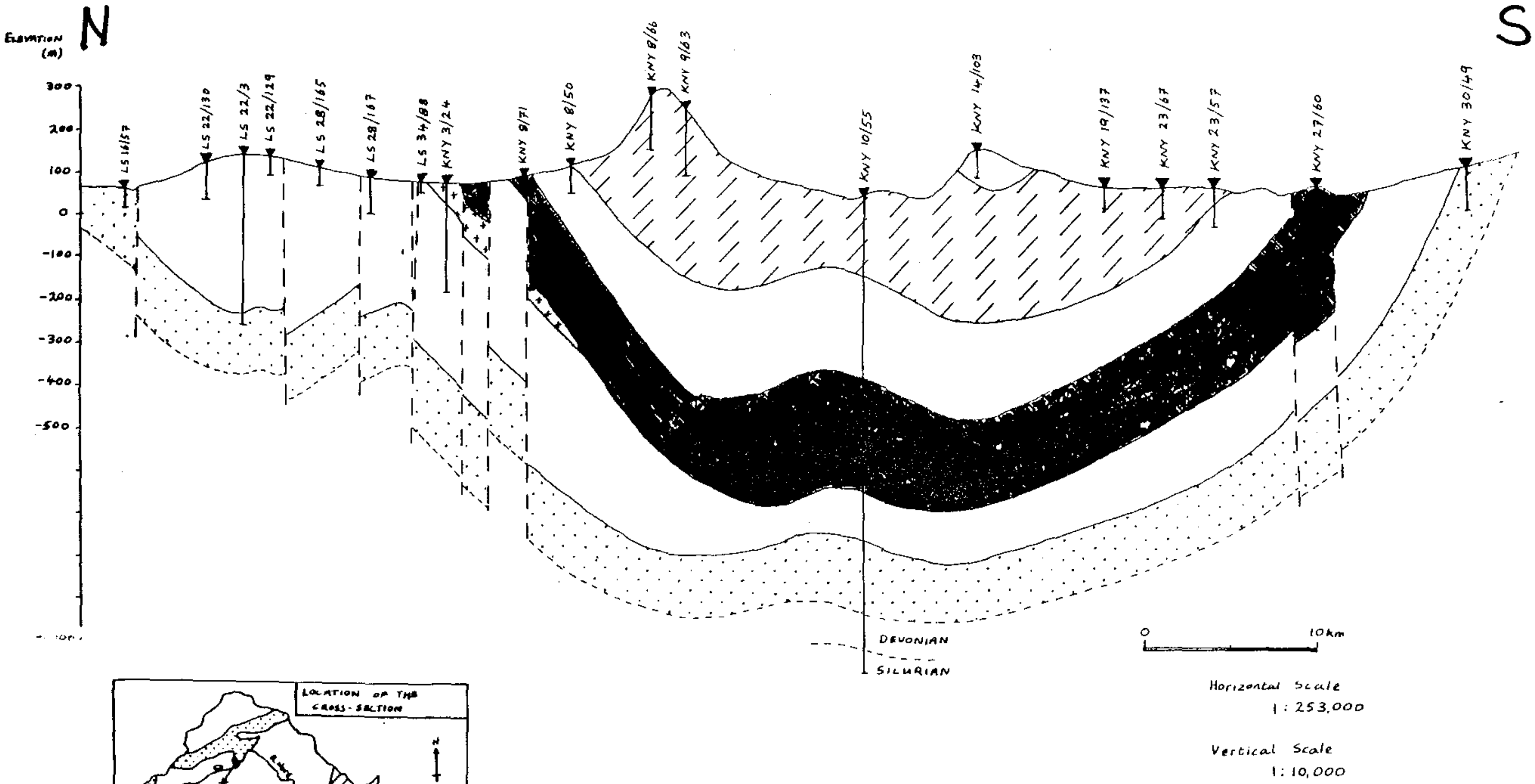
Little is known of the detailed extent and distribution of this mineralization. No estimates of the tonnage and grade of the copper mineralization are included in the reserve estimates.

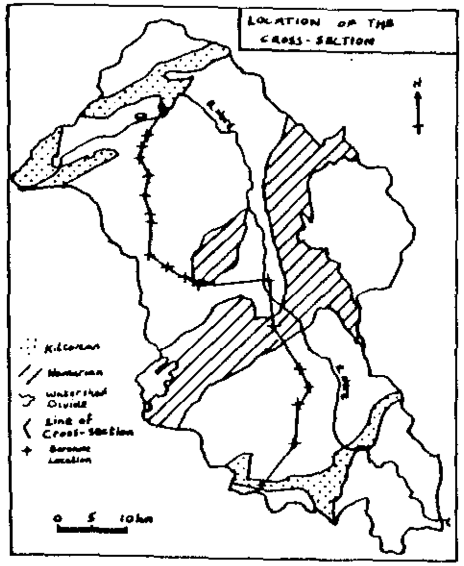
Conclusions

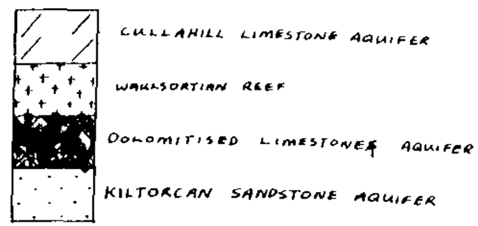
The style, textures and form of the zinc-lead mineralization at Galmoy indicate that it is stratabound replacement mineralization. The sequence of events leading up to the formation of the Galmoy deposits and their subsequent modification is summarized in Figure 6. It must be emphasized that this initial interpretation is based mainly upon macroscopic examination of drill core and a detailed paragenetic sequence and interpretation must await a more rigorous examination.

The Waulsortian Limestone was deposited in the late Courceyan, and although the original

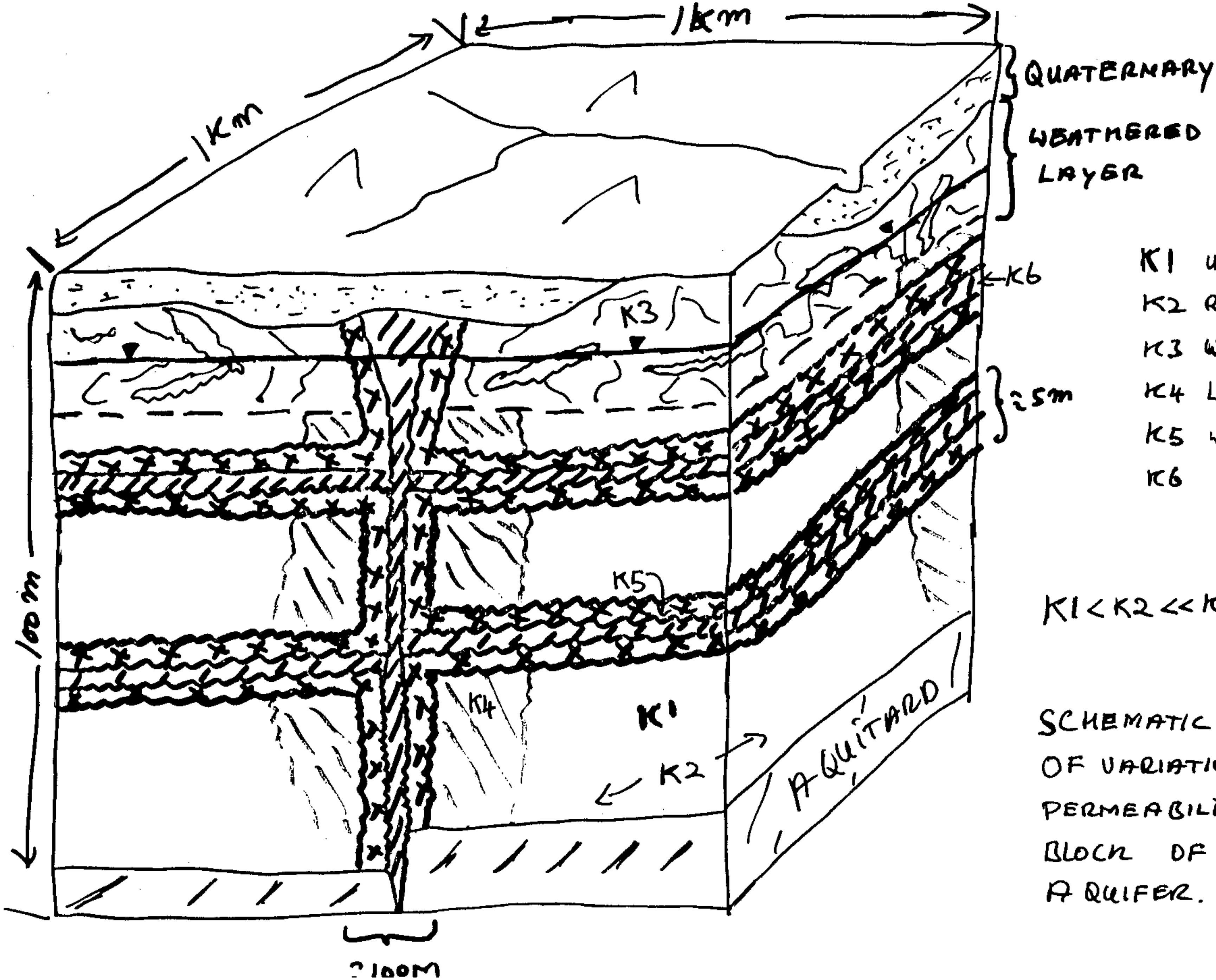
OH7







CROSS-SECTION OF THE NORE RIVER BASIN



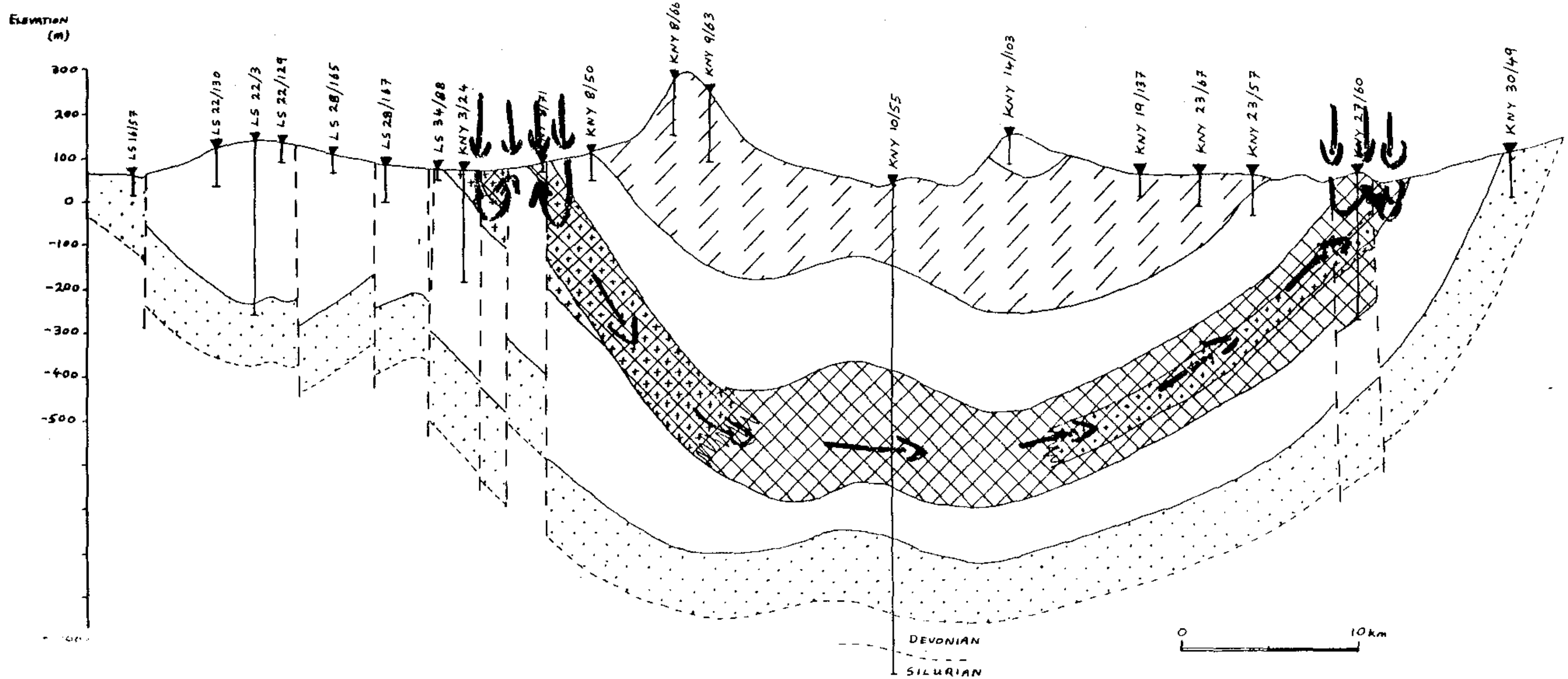
K1 UNDOLOMITISED LIMESTONE
K2 REGIONAL DOLOMITISATION
K3 WEATHERED LAYER
K4 LATE DOLOMITISATION
K5 WEATHERED/SOLUTION/BROKE
K6 FAULT/PERMEABLE HORIZON

$K1 < K2 \ll K3 < K4 \ll K5 < K6$

SCHEMATIC DIAGRAM OF VARIATION IN PERMEABILITY IN A BLOCK OF A DOLOMITE AQUIFER.

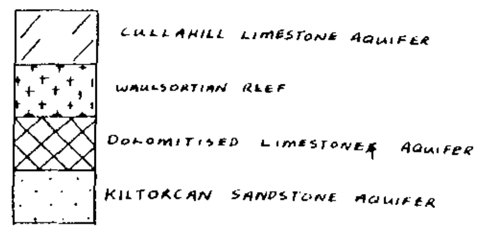
AREA	STRATIGRAPHIC HORIZON	WELL YIELD m^3/D	SPECIFIC CAPACITY $m^3/d/m$	TRANSMISSIVITY m^2/d
ATHY	LT. AGHMACART → UPR. BALLYSTEEN (EQUIV)	1,000–1,500	50-100	100-200
CARLOW	CROSSPATRICK → LR. BALLYSTEEN (EQUIV)	700–2,620	40-130	80-300
BAGENALSTOWN	LR. BALLYSTEEN	500–1,000	40-80	60-120
NORE RIVER BASIN	LR. AGHMACART → UPR. BALLYSTEEN	160–260	50-80	100-150
GALMOY (ARCON, 1992)	WAULSORTIAN	310–2850	10-260	50-600
PORTLAOISE (LAOIS Co.)	CROSSPATRICK (EQUIV) → WAULSORTIAN	2,350–4,420	180-280	400-600
S. WEXFORD (CULLEN, 1978)	CROSSPATRICK (EQUIV.) → BALLYSTEEN	1,110–1,200	40-75	50-100

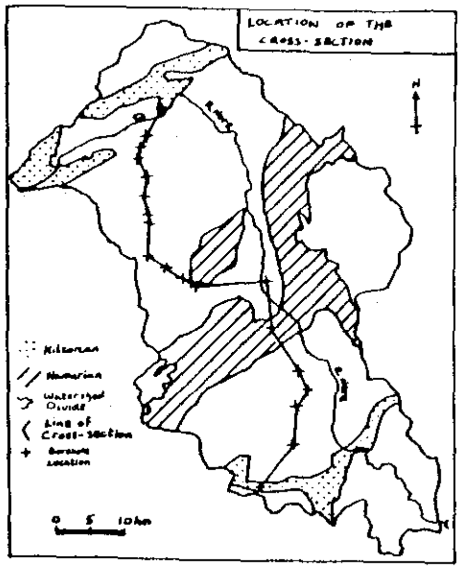
PUMPING TEST RESULTS FROM BOREHOLES IN THE AREAS WHERE THE DOLOMITE AQUIFER HAS BEEN DEVELOPED.



Horizontal Scale
1 : 253,000

Vertical Scale
1 : 10,000





CROSS-SECTION OF THE NORE RIVER BASIN

OH 11

FEATURES WHICH SUGGEST DEEP GROUNDWATER FLOW IN THE DOLOMITE AQUIFER BETWEEN THE TWO LOWLAND AREAS OF THE NORE RIVER BASIN.

(1) **The aquifer is continuous at depth under the centre of the basin.**

(2) **There is significant permeability at depth.**

(3) **There is a head difference between the discharge levels in the two lowlands in excess of 30m which could provide the hydraulic drive.**

(4) **The large springs in the Callan-Bennettsbridge Lowlands through which the aquifer discharges.**

(5) **The slightly elevated temperatures of some of the discharge waters from this aquifer in the Callan-Bennettsbridge Lowlands.**

OH 12

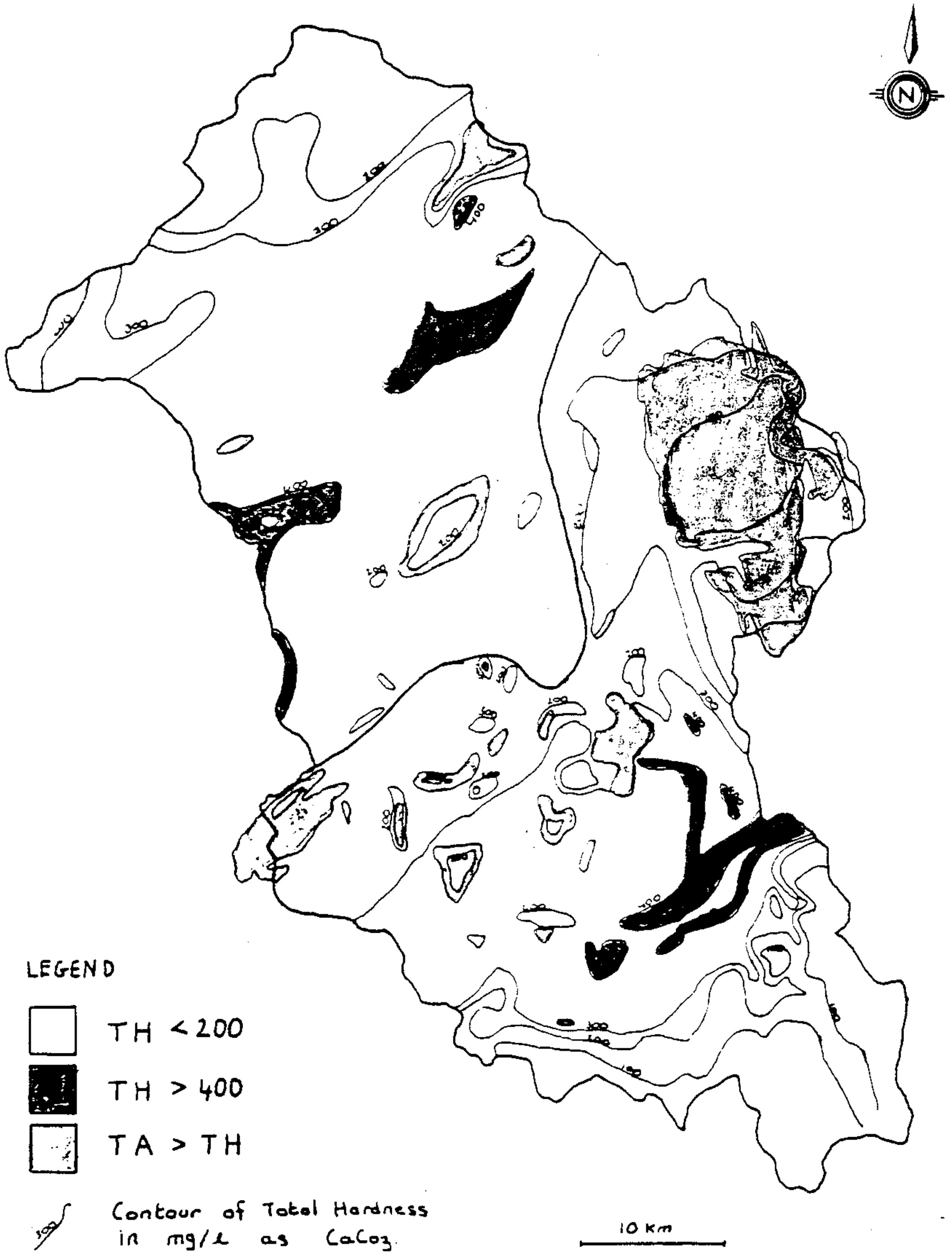


Figure 7. Distribution of Total Hardness (TH) in the Bedrock Formations of The Nore River Basin.

OK 13

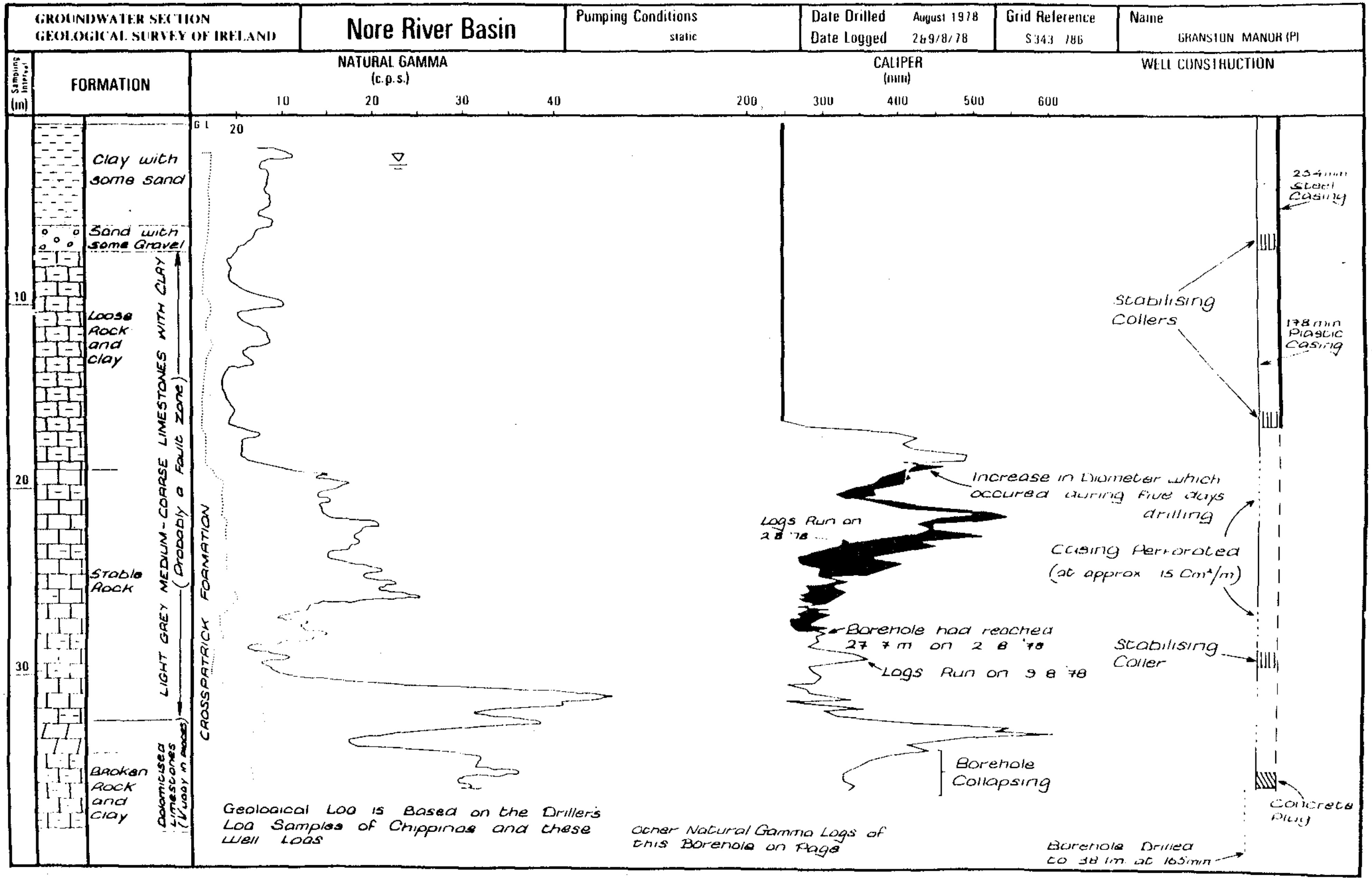


Figure Geophysical Well Logs of Borehole LS 28/170

OH14

APPENDIX 2

COPIES OF SLIDES USED IN THIS LECTURE

(IAHDOLOM.LCT)

GSI LOGO

1

BALLYLANIGAN CORE

S.E TIPP.
DOLOMITE

BALLYLANIGAN CORE

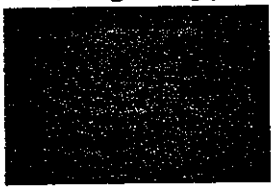
'VUGS' IN DOLOMITE

BALLYLANIGAN CORE

CLAY FILLED FISSURE IN DOLO

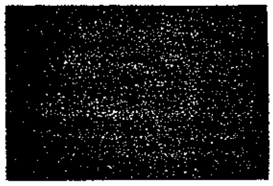
4

RATH DUFF RESILS CORE



VUGS IN DOLOMITE

10 20/XI/'86



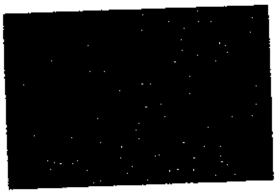
QUARRY AT TRUMRA (Q.I)
REEF (BASE) CO. LAOIS

24 20/XI/'86

OUTCROP AT RUSELL, Co. LAOIS
BASE OF DOLOMITISED REEF

7

30 20/XI/'86



FENNOR HILL
SITE III

27 20/XI/'86

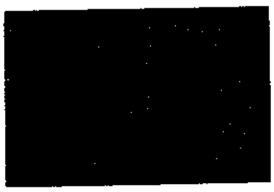
FENNOR HILL
NORTH SIDE OF CUT.

KEDRAH. S.TIPP

SPRINGS

10

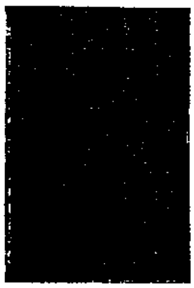
7 19/XI/'86



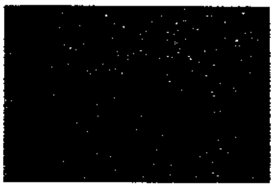
BAUSHEENMORE WELLS
OUTFLOW FROM SPRING V

DEEP GW. FLOW

KILT. SST.



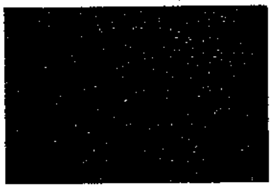
DRILLING AT LISHEEN



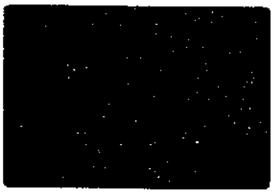
Co. TIPP. JULY '92

13

DRILLING AT LISHEEN.



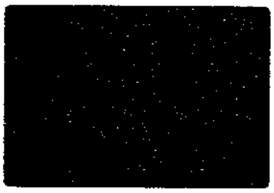
Co. TIPP. JULY '92



MAY '92

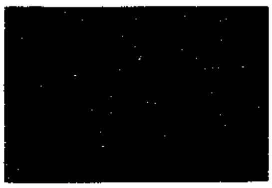
15 MINCH NORTON - ATHY
USE OF REVERT

MAY '92



MINCH NORTON - ATHY

THE LADS +
OLD PUMP



Large Scale Pumping Tests.

Presented by: Kieran O'Dwyer (K.T. Cullen & Co. Ltd)

An essential part of groundwater resource evaluation is the carrying out and analysis of pumping tests. Pumping tests provide valuable information on the characteristics of the aquifer under investigation together with an assessment of the performance of the individual wells and the impact of the proposed abstraction on the aquifer. In cases where the intended abstraction is large a thorough and comprehensive pumping test programme must be undertaken. In order to illustrate the various aspects of these tests, an extended multi-well pumping test carried out at Galmoy in North Kilkenny has been used as a case study.

Introduction.

In cases where a development intends to abstract very large quantities of water, the execution of a comprehensive pumping test becomes essential. The test must be designed to examine all the potential impacts of the abstraction. The types of development that require detailed pumping test as outlined below are large regional water supply schemes, mine and quarry dewatering projects and environmental impact studies for developments where the abstraction from the aquifer is such that it will have a regional impact on the surrounding area. Groundwater when properly managed is a renewable resource, however in certain instances an aquifer can be over developed to the extent that the annual abstraction may be greater than the annual recharge. Large scale developments may also alter the flow pattern of the groundwater to such an extent that seemingly remote contaminant sources (such as landfills) may be drawn into the system. The information gleaned from these extended large scale pumping tests is usually required to form the basis of a numerical mathematical model (both to provide the input characteristics and to provide a scenario against which the model can be calibrated). Some developments when implemented will pump such large quantities of groundwater that the desired abstraction rate cannot be pumped during the test due to the lack of electrical power available to run the pump or the fact the impact of the test itself would be unacceptable.

Pre-Test Preparation.

Large scale extended pumping tests can have a significant effect on the surrounding area and contingincies must be put in place in order to minimise the disruption to the neighbouring landowners. These tests are costly and stoppages will seriously devalue the quality of the data that is being collected.

There are a number of steps that must be taken prior to any pumping taking place.

i) A survey of all wells within a radius of 3-5 kilometres (depending on the geology) of the wells under test should be conducted. This radius should be greater than that area which it is estimated will be effected. These wells should be monitored regularly for three weeks prior to the test in order to establish any seasonal trend in the regional water table.

ii) A number of remote wells should be chosen that will lie outside the predicted influence of the wells under test. These will serve to monitor any natural changes in the water table that may occur during the test. Digital recorders should be installed if they are available.

iii) The water level should be measured in selected wells throughout the aquifer. These will allow the the regional water table within the aquifer to be contoured. These water table contours from an important part of the modelling process. The model is first calibrated to match the water table.

iv) The risk of drying out local domestic wells must be assessed and a contingincy plan must be decided upon in order to maintain water supply to households that are affected.

v) The surface drainage network must also be inspected and the risk of drying up assessed in order that measures to replace water supply to livestock can be implemented.

vi) Temporary wiers should be constructed in strategic locations along streams within the area of investigation in order to quantify the impact on stream flow. The flow in these streams should be monitored regularly for a period of at least three weeks prior to the test.

vii) Sites must be chosen for the discharge from the pumping wells. These sites should be located as far from the wells under test as is practical or to such a location where the risk of recharge is minimised. Right of way for the discharge pipes must be agreed with local landowners. Where possible V notch weirs should be constructed at the discharge points in order to provide a backup for discharge measurement in the event of flowmeters not functioning.

viii) In large scale pumping tests the data from observation wells is more important than the data from the pumping wells themselves. Ideally observation wells should be located at distances of 50, 100, 200, 400, and 800 metres from each pumping well. If more are available then the data collected will be of a higher quality.

ix) If a rock aquifer is being investigated, at least one shallow observation well within the overburden should be drilled at each site. This will enable the hydraulic relationship between the bedrock and the overburden to be determined.

x) All the residents within the the area should be informed when the test is taking place, the probable impacts and the measures that will be taken in the event of domestic wells drying out. The owners of the wells that are considered high risk should be visited and and agreement reached regarding the replacement supply.

Pumping Test Procedure.

Prior to the running of the extended pumping test each well should be individually tested for a period of 72 hours. A step test should also be carried out on each well. An extended large scale pumping test was carried out at Galmoy Co. Kilkenny during the summer of 1992. Shorter pumping tests had been carried out previously in 1989. I will use the 1992 test as an example to illustrate the procedure. The pumping test at Galmoy was carried out primarily to investigate the impact of the proposed mine dewatering on the surrounding area. A monitoring network comprising some 101 wells was used. These wells fell into several catagories.

Observation Wells.
Wells that were drilled specifically to provide drawdown information. Some of these were completed within the overburden.

Mineral Exploration Boreholes.
39 of the mineral exploration boreholes drilled had standpipes installed and were incorporateed into the water level monitoring network.

Domestic Wells.
49 domestic wells were monitored before and during the test. These wells were both shallow and deep. A digital water level recorder was installed in a disused domestic well to the north of the area of interest. This well was chosen because it would not be impacted on by the pumping test. The well would provide a base line on the natural fluctuation in the regional water table which would help in distinguishing between the natural drawdown and that due to the pumping wells.

The extended pumping test involved pumping two production wells PW 1and 2 simultaneously at the highest rate possible, as determined by the finished diameter, for a continuous period of 8 weeks. The pumped water was discharged 800 m and 1200 m from each well.

The monitoring of the pumping test included a range of measurements.

- Flow, pH, conductivity and temperature at each well head.
- Water levels in the two pumping wells, 13 Observation wells, 39 mineral exploration boreholes and 49 domestic wells.
- Stream flows using temporary weirs.
- Digital and continuous chart recorders.
- Regular chemical and bacteriological analyses.

In addition to the above, the following logistical items were an integral part of the test

(a) the provision of replacement domestic and agricultural water supplies.
(b) the replacement of the Rathdowney water supply.
(c) sampling and analysis of replacement water supplies.

Pumping Test Schedule

Table 1. outlines the test schedule with PW 2 starting pumping one day before PW 1. Both wells were then pumped simultaneously for 56 days at a combined rate of approximately 185m^3/hour.

Table 1. Pumping rates recorded during 1992 extended pumping

Week	Average Pumping Rate (m3/hour)	
	PW1	PW2
July 27 - August 2	66	123
August 3 - August 10	64	122
August 11 - August 17	66	120
August 18 - August 24	66	122
August 25 - August 31	65	119
September 1 - September7	65	119
September 8 - September 14	64	118
September 15 - September 21	64	118
September 22 - September 28	64	118
September 29 - October 5		118
October 6 - October 12		118
October 13 - October 19		118
October 20 - October 27		118

Cone of depression

The withdrawal of $185m^3$/hour from the dolomite aquifer at PW's 1 and 2 generated a cone of depression centred on the pumping wells. The drawdown contours used to define the extent of the cone were corrected for the seasonal lowering of the water. This seasonal lowering was observed in the remote monitoring stations and and was also determined from the slope of each recession curve prior to the start of the pumping test. As the water table fell naturally (in excess of 1m) during the test, the extent of the 0.5m contour is somewhat subjective and the only wells used to delineate the cone were those where the onset of the pumping test was clearly defined in the well hydrographs.

The lowering of the water table impacted on the local stream network. Measurements taken at 10 temporary weirs demonstrated that the extended test effectively dried up some small streams that rise close pumping wells. While some of the small streams were impacted by the dewatering, the onset of wet weather conditions resulted in storm flows in all the streams monitored.

The shape of the 6 week cone reflects the known geology of the area with the cone elongated in a north south direction. In addition, the high transmissivity zone along the western edge corresponds with the extension of the 5m contour towards the G-Fault. As no effect was detected at the observation wells to the south of the G-Fault, this feature is seen to act as an impermeable boundary seperating the dolomite from the Ballysteen inlier.

Time Drawdown Data

An analysis of the early time drawdown data (< 1000 minutes) from the piezometers and observation boreholes close to the pumping wells provide the transmissivity values listed in Table 2. These results generally correspond with the pattern determined from the previous tests carried out in 1989.

Table 2. Aquifer characteristics for dolomitised Waulsortian dolomite.

Pumping Well	Observation Well	Transmissivity (T) m^2/day 1989*	1990**	1992**	Storage (S)
PW2	Well 86		700	618	3.7 / 7* x 10^{-4}
PW2	Well 85	350	294		2 / 4* x 10^{-4}
PW2	OW2	290	295	359	3.5/5.5* x 10^{-4}
PW2	OW 8			552	
PW1	Well 112	267		302	4 x 10^{-4}
PW1	OW1	49		66	2 x 10^{-4}

*** Single Well Test ** Combined Test**

The analysis of the pumping test data indicates recharge or leakage conditions. Boundary effects are indicated by the increase in the slope of the time-drawdown curves.

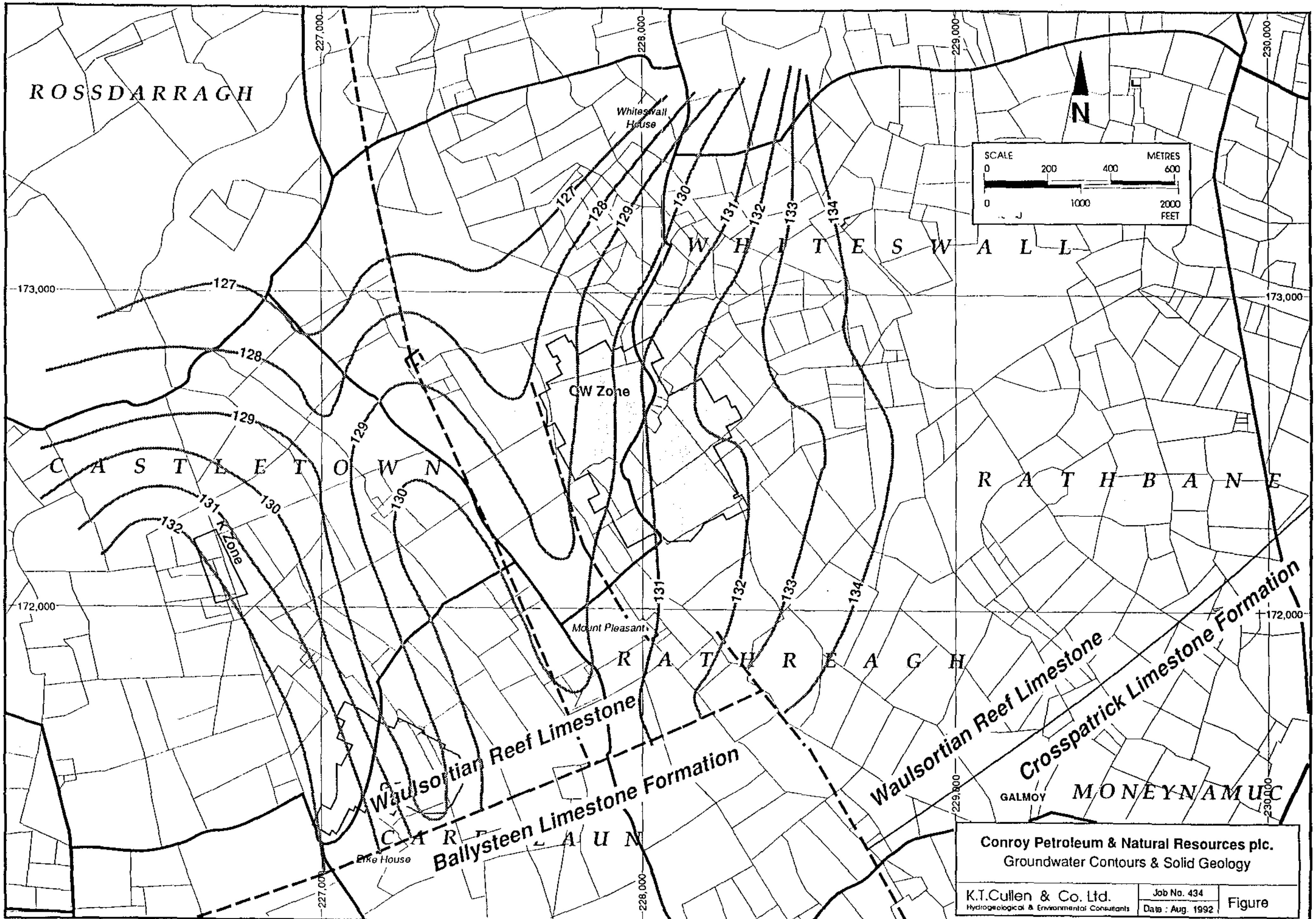
The time-drawdown curves for the two pumping wells and some nearby observation wells show little sign of reaching equilibrium at the end of the extended test due to the compartmentalised nature of the aquifer.

The impact of the pumping test on the regional water table resulted in three wells drying up as predicted. A water supply was made available to the effected households. Two streams dried up for short periods during the test and alternative supplies had to be made available for livestock. The Rathdowney water supply was maintained using some of the discharge water from the pumping test.

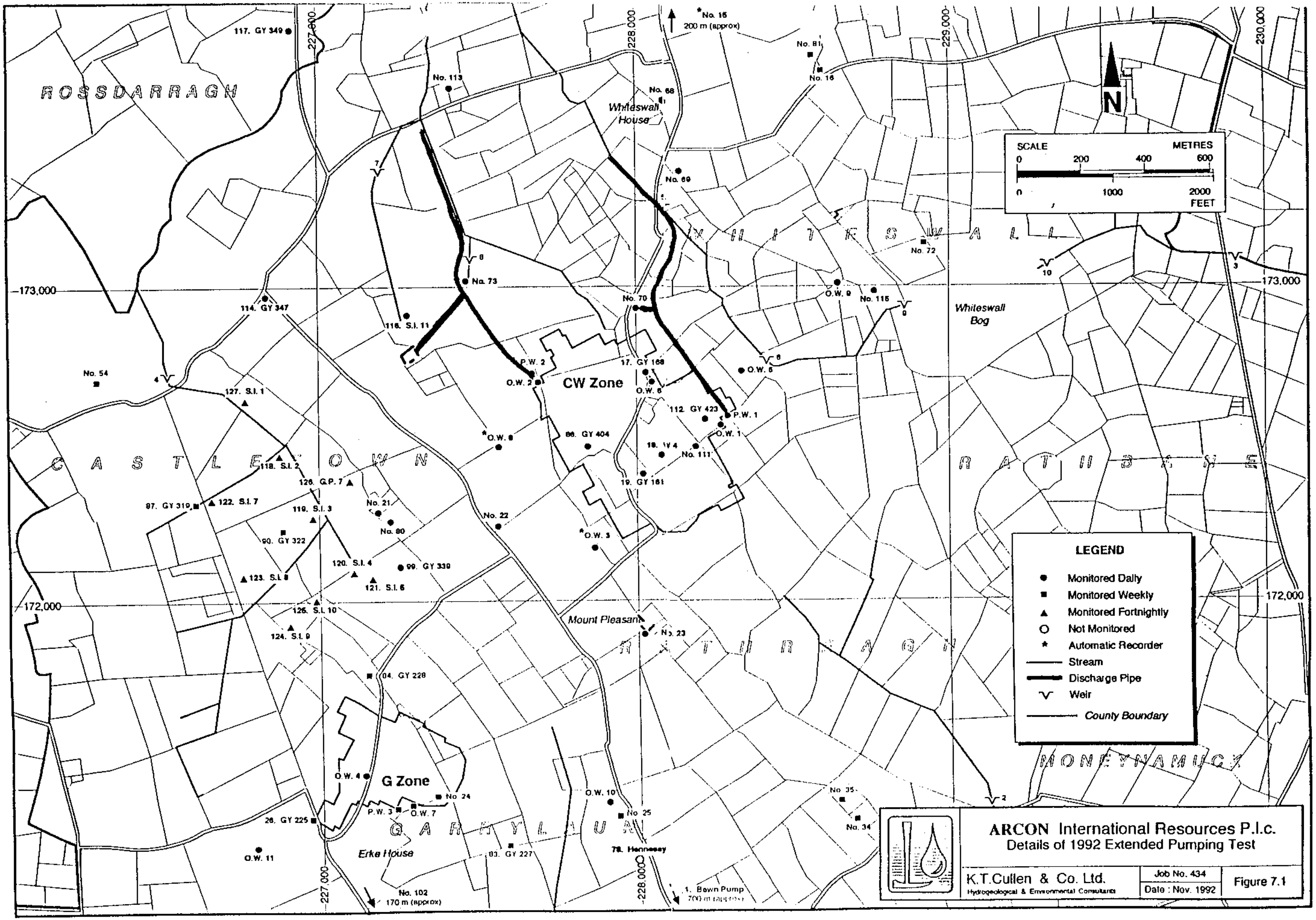
An analysis of all the pumping test data concludes,

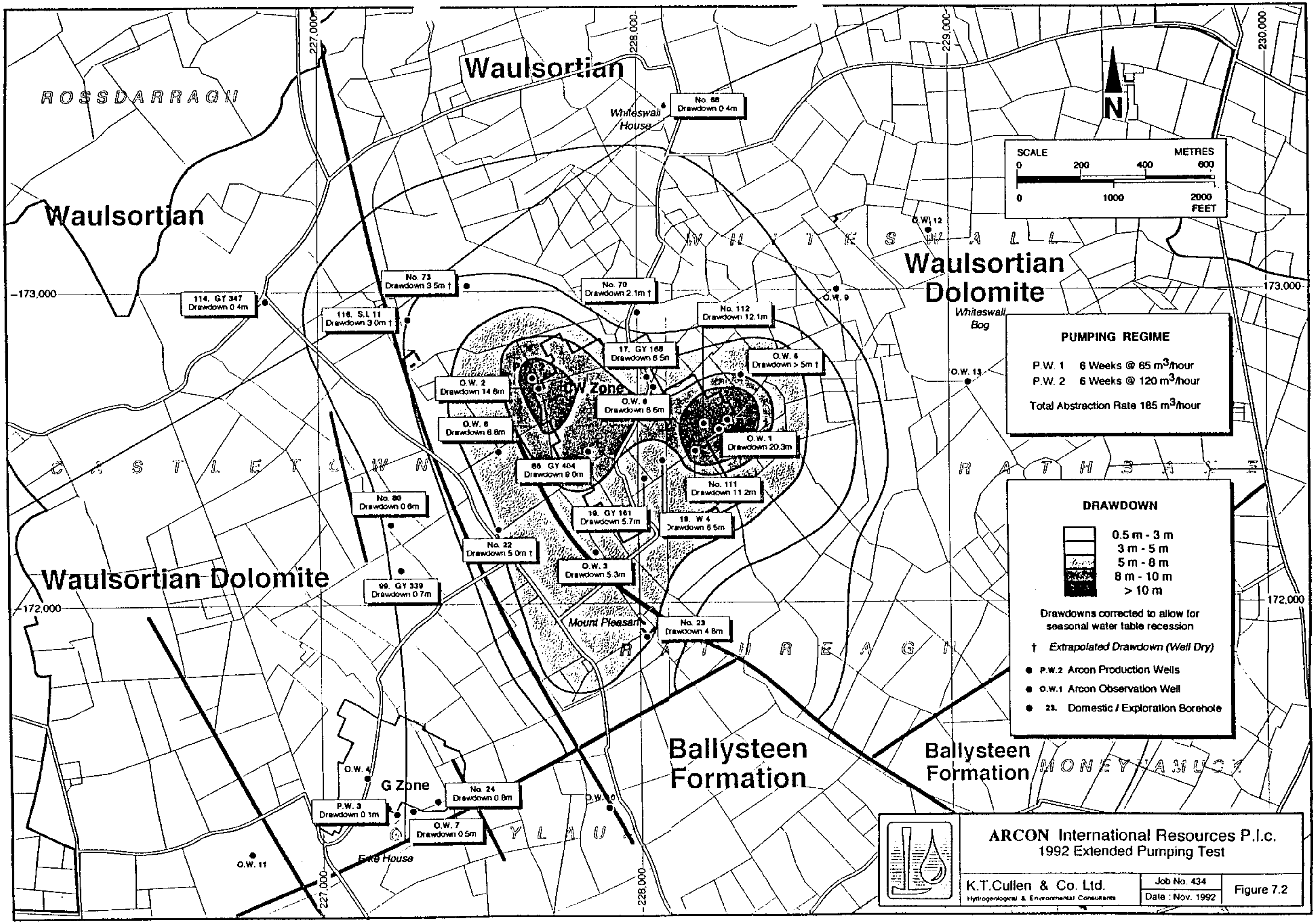
- The aquifer is heterogeneous
- The eastern side of the well field, represented by PW 1, has transmissivity values in the range 40-160m^2/day, while the western side, represented by PW 2 has transmissivity values of about 260-600m^2/day.
- The G fault acts as an impermeable boundary.

The results of the test were then incorporated into a numerical model which was used to predict the long term impact of a full scale dewatering programme. This permits the steady state condition to be predicted. In large scale developments it may take several years for steady state to be achieved. In steady state all the discharge comes from recharge as the groundwater within the dewatered area has been removed from storage.



ROSSDARRAGH
Whiteswall House
WHITESWALL
CASTLETOWN
RATHBANE
RATHREAGH
CARRIGEAUN
MONEYNAMUC
GALMOY
CW Zone
K Zone
Mount Pleasant
Eike House
N
SCALE
METRES
0 200 400 600
0 1000 2000
FEET
127
128
129
130
131
132
133
134
227,000
228,000
229,000
230,000
173,000
172,000
Waulsortian Reef Limestone
Ballysteen Limestone Formation
Crosspatrick Limestone Formation
Conroy Petroleum & Natural Resources plc.
Groundwater Contours & Solid Geology
K.T.Cullen & Co. Ltd.
Hydrogeological & Environmental Consultants
Job No. 434
Date : Aug. 1992
Figure


ARCON International Resources P.l.c.
Details of 1992 Extended Pumping Test
K.T.Cullen & Co. Ltd.
Hydrogeological & Environmental Consultants
Job No. 434
Date : Nov. 1992
Figure 7.1
LEGEND
Monitored Daily
Monitored Weekly
Monitored Fortnightly
Not Monitored
Automatic Recorder
Stream
Discharge Pipe
Weir
County Boundary
SCALE
METRES
0
200
400
600
0
1000
2000
FEET
N
ROSSDARRAGH
CASTLETOWN
WHITESWALL
RATHBANE
RATHREAGH
MONEYNAMUCK
GARRYLAUN
CW Zone
G Zone
Whiteswall House
Whiteswall Bog
Mount Pleasant
Erke House
227,000
228,000
229,000
230,000
173,000
172,000
No. 15
200 m (approx)
117. GY 349
No. 113
No. 68
No. 81
No. 16
No. 69
No. 72
No. 73
No. 70
O.W. 9
No. 115
114. GY 347
116. S.I. 11
No. 54
127. S.I. 1
P.W. 2
O.W. 2
17. GY 168
O.W. 6
O.W. 5
112. GY 423
P.W. 1
O.W. 1
O.W. 8
86. GY 404
18. W 4
No. 111
19. GY 161
118. S.I. 2
126. G.P. 7
87. GY 319
122. S.I. 7
No. 21
119. S.I. 3
No. 80
90. GY 322
No. 22
O.W. 3
120. S.I. 4
99. GY 339
123. S.I. 8
121. S.I. 6
125. S.I. 10
124. S.I. 9
No. 23
104. GY 228
O.W. 4
No. 24
P.W. 3
O.W. 7
26. GY 225
O.W. 10
No. 25
O.W. 11
83. GY 227
78. Hennessy
No. 35
No. 34
No. 102
170 m (approx)
1. Bawn Pump
700 m (approx)



Waulsortian
ROSSDARRAGH
No. 68 Drawdown 0.4m
Whiteswall House
N
SCALE METRES
0 200 400 600
0 1000 2000 FEET
Waulsortian
O.W. 12
WHITESWALL
Waulsortian Dolomite
Whiteswall Bog
No. 73 Drawdown 3.5m †
No. 70 Drawdown 2.1m †
114. GY 347 Drawdown 0.4m
116. S.I. 11 Drawdown 3.0m †
No. 112 Drawdown 12.1m
O.W. 9
17. GY 168 Drawdown 6.5m
O.W. 5 Drawdown > 5m †
O.W. 13
O.W. 2 Drawdown 14.6m
W Zone
O.W. 6 Drawdown 6.6m
O.W. 8 Drawdown 6.8m
O.W. 1 Drawdown 20.3m
PUMPING REGIME
P.W. 1 6 Weeks @ 65 m3/hour
P.W. 2 6 Weeks @ 120 m3/hour
Total Abstraction Rate 185 m3/hour
CASTLETOWN
66. GY 404 Drawdown 9.0m
No. 111 Drawdown 11.2m
RATHBAYE
No. 80 Drawdown 0.6m
19. GY 161 Drawdown 5.7m
18. W 4 Drawdown 6.5m
DRAWDOWN
0.5 m - 3 m
3 m - 5 m
5 m - 8 m
8 m - 10 m
> 10 m
No. 22 Drawdown 5.0m †
O.W. 3 Drawdown 5.3m
Waulsortian Dolomite
99. GY 339 Drawdown 0.7m
Drawdowns corrected to allow for seasonal water table recession
Mount Pleasant
No. 23 Drawdown 4.8m
RATHREAGH
† Extrapolated Drawdown (Well Dry)
P.W.2 Arcon Production Wells
O.W.1 Arcon Observation Well
23. Domestic / Exploration Borehole
Ballysteen Formation
Ballysteen Formation
MONEYNAMUCK
O.W. 4
G Zone
No. 24 Drawdown 0.8m
P.W. 3 Drawdown 0.1m
O.W. 7 Drawdown 0.5m
O.W. 10
O.W. 11
Elite House
227,000
228,000
229,000
230,000
173,000
172,000
ARCON International Resources P.l.c.
1992 Extended Pumping Test
K.T.Cullen & Co. Ltd.
Hydrogeological & Environmental Consultants
Job No. 434
Date : Nov. 1992
Figure 7.2

GROUNDWATER DEVELOPMENT IN

NORTH CORK

Talk to I.A.H., Portlaoise,
April, 1993.

Pat Walsh, B.E., C. Eng., M.I.E.I.
Executive Engineer,
Cork County Council (North Cork Division)

C O N T E N T S:

P A R T I

P A R T II

Development of New Sources

PART I

1.1 Existing Water Supply Sources in North Cork

The predominant characteristics of the water supply sources in North Cork are

(a) that there are a large number of individual sources

(b) that the majority of the sources are from groundwater.

1.1.1 Number of Sources

In total, there are 67 separate water sources in use in North Cork to serve a population of 75,000 people in an area of approximately 1,000 sq. miles. Many of these are small supplies serving group schemes and small pressure pumps in the rural areas. The twelve larger schemes would account for approximately 50% of the daily usage.

1.1.2 Quantity

The daily water consumption in the Division is approximately 5.4 mgd (24,550 m^3/d). The sources can be classified as follows:

(1) Springs - Over half the daily usage comes from naturally occurring springs (56%). Examples of the bigger springs are Ballinatona spring (N.W. Reg.) 5,800 m^3/d, Doneraile/Buttevant supply 1,910 m^3/d, Castletownroche 1,364 m^3/d,

(2) Bored Wells - About 34% of the daily consumption is supplied from bored wells of which the largest are: Charleville 2,300 m^3/d and Mitchelstown 2,600 m^3/d.

(3) River Abstractions - The remaining 10% of the daily usage is made up of 3 river schemes, the Allow River at Freemount 600

m^3/d, the Clyda River at Mallow 3,000 m^3 /d and the Bride River at Castlelyons 900 m^3/d.

1.1.3 Potential Groundwater Quantities

It is worthy of note that the above figures represent only the present usage whilst the yields of many of these sources is far greater thus allowing expansion in the future. For example, the figure for Charleville of 2,300 m^3/d is the present daily flow, whilst the three bored wells in the scheme, have been pump tested to yield a flow of almost 9,100 m^3/d (2,000,000g/d). Thus it can be seen that the figures mentioned above do not represent the great potential for expansion there is in many of the schemes.

There are vast areas of North Cork which are defined as zone 2 aquifers. Part II of this paper gives an example of a large scheme recently developed which is capable of supplying several million gallons of water daily. There are a few hundred square miles of zone 2 aquifers in the Division, so without a detailed study it is not possible to estimate the vast groundwater potential in the North Cork Division.

1.2 Aquifer Protection Schemes

1.2.1 The Geological Survey of Ireland have correctly stressed the importance of protecting the groundwater resources in Ireland from the many types of pollution that can arise. Mr. Donal Daly has presented many papers on this, which have been most helpful to local authorities. Many of his recommendations have been implemented now for some years by Cork County Council.

1.2.2 Aquifer Protection Zones

All of the bigger supplies in North Cork have had a detailed aquifer protection study performed by a hydrogeologist. Particularly in the limestone aquifers, details of disappearing streams, swallow holes, low overburden cover, the fissured nature of the rock structure, etc., are all very relevant features which need to be taken into account in protecting the aquifer. Maps showing the zone 1 aquifers, together with details of zone 1(b) and zone 1(c) areas are kept, not only in the area engineer's office, but especially in our central Planning Department Offices where proposed developments are checked against these aquifer zones. In some cases, planning permission has been refused, while in other instances, additional conditions may apply.

1.2.3 Internal Training Courses

Over the last 3 years, a number of 'training days' have been held for our own staff, e.g. water curators, etc. in which particular attention is given to the role everybody has to play in protecting our water resources. This vigilance is just as important where there are groundwater sources as with river abstractions because, even though the groundwater is not as vulnerable to pollution, nevertheless if pollution does enter an aquifer, then it can be almost impossible to clear it. There are probably few instances where the maxim "prevention is better can cure" is more apt.

1.2.4 Sludge Injection

North Cork is located, like all inland counties, away from the sea, so that disposal at sea was never an option for sludge disposal from either municipal sewage works or from private industry. In order to assist the protection of our aquifers, soil injection of sludge is now being carried out for the disposal of the Council sludge.

Licensing of industry for the disposal of sludge by soil injection, on previously surveyed farms, is now on-going. This licensing is done under the Waste Regulations.

In the overall context of aquifer protection, it behoves us all to protect the water cycle so that it can be passed on to future generations in the condition we have received it.

1.3 Water Level Monitoring

1.3.1 Borehole Water Levels

The winter of 1991/92 was drier that usual and, as a result, the water table actually dropped during a period when the aquifer should be recharging until mid-March. Weekly dippings have been taken on 6 wells since 1991 and also on another 5 wells fortnightly. This data has been logged on computer and in the relative short history of taking these levels, they have proven very useful.

1.3.2 Rainfall Recording

In the North Cork area, six council employees record rainfall levels daily for the Meteorological Office. This information is then available to the Council for its own use and is very valuable in predicting the possibility of water shortages, etc.

1.3.3 Combination of Rainfall and Water Level Records

There is much merit in looking at the water cycle as a unit. To that end, a number of internal reports were written in the spring of 1992, analysing rainfall records over the winter and water levels in boreholes. Indeed in April, 1992, the council informed its elected members that water levels were particularly low at the end of the recharge period and that if the summer ahead was warm and dry that water shortages would be experienced in the autumn. As the 'summer' developed, however, there was 4" of rain in July, 5" in August and 4" in September, so no problem arose.

Records for the past winter, 1992/93 now show a similar trend if not indeed worse. The end of March water table levels are equivalent to the early May levels of last year. If this summer ahead is dry, then problems with the effect of pollution, the drying of small springs etc. are likely to occur.

Last year, 1992, a list of water schemes that could be affected was drawn up and a strategy decided even in June as to what measures to be taken in the event of shortages. This we feel represents good planning.

1.3.4 Data Recording/Collection - The Future

The value of having groundwater data has been shown clearly to us in the past year. With that in mind, we have been examining options for the use of data loggers for recording water levels and also rainfall. We have had two types of datalogger on trial and indeed used them for a well pumping test recently. We have received quotations for a system and hope to purchase a number of dataloggers this year. Eventually, they will be linked by telemetry to the central Council offices in Mallow. It is estimated that the labour savings on **one** prolonged pump test would pay for a mobile datalogging unit!

PART II

Development Works for New Groundwater Schemes

2.1 Mallow/Ballyviniter Water Supply

2.1.1 Existing Water Supply

Presently the water needs of the town of Mallow are being served by a water abstraction from the River Clyda, a tributary of the Blackwater River. A smaller source from a nearby lake also contributes to the supply as required.
There have been many operational problems with both sources, particularly from pollution of the River Clyda which can occur several times each year. Attention was given in 1990 to the location of a suitable groundwater supply to serve the town of Mallow adequately for the foreseeable future.

2.1.2 Location of Source - Test Wells

A consultant hydrogeologist, Geoex Ltd., was retained in 1986 to do a desk top study as to whether it was feasible to search for a groundwater source close to Mallow. The source would at least have to serve the immediate needs of the area of almost 1 million gallons/day. (4,550 m^3/d).

In 1990, the Council decided to go ahead with some site investigations. Trial boreholes were drilled in the aquifers around Mallow. Test wells were drilled in the reef limestones east of Mallow, in the Devonian Sandstones in the Clyda Valley (near the existing river intake works) and the sandstones in Rahan. These wells yielded estimated flows of 1,000 - 4,000 gph and, therefore, did not deem any further testing. Exploration wells were drilled north of Mallow in the limestone aquifers at Ballybeg Quarry near Buttevant and in the limestones near Doneraile at Box Cross. Two wells were drilled at Buttevant one of which was abandoned, the other though was quite promising, so it was pump tested. This test well was 150mm diameter, drilled and lined to a depth of 31m. Pump testing proved that the drawdown was just 7m at the maximum pumping rate of the pump of 9,200 gph (42 m^3/hr). This was most encouraging.

An exploration well drilled near Box Cross was similarly encouraging, again achieving the maximum output of the test pump, but with only a drawdown of 1.1m. All these wells were drilled by Dunne's Welldrilling (Mallow) Ltd.

2.1.3 Production Wells

It was then decided to drill a production well in Box Cross, Doneraile, which was completed in 250mm UPVC liner to a depth of 30m. Test pumping was carried out in May, 1991 and a flow of 30,000 gph (136 m^3/hr) was achieved at a drawdown of 7m. This suggested that this well alone would meet the present demand of Mallow town. Two other test wells were then drilled in the same aquifer nearby. Both of these were also very encouraging and were pump tested to give flows of approximately 15,000 gph (68 m^3/hr) each, at low drawdowns. It was then decided that production wells for both these test wells would also be drilled and this was done during the summer of 1991. These were completed in 250mm UPVC liner to depths of 46m and 55m and were drilled by Dunne's Water Services Ltd.

These three production wells in the Box Cross area, Doneraile are all drilled in a faulted zone between the Reef Limestone and the Copstown Limestone formation.

2.1.4 Well Pumping Tests

During the summer of 1991, it was decided that a detailed pump test would be simultaneously carried out on these three production wells. Initial testing, as mentioned above, suggested that the wells had a possible capacity of 30,000 + 15,000 + 15,000 gph which, if ran simultaneously, may have a major affect on the aquifer. It was decided, therefore, that in areas of the aquifer where there were no private wells available for monitoring, that observation wells would be drilled to below the water table level, solely for monitoring purposes. These observation wells were drilled and dipping of these levels began weekly so that a history of the water table levels would be established before well pump testing began.

Test pumping on the three production wells began on 7th October, 1991. All three were started almost simultaneously. Water levels were recorded using an electric dipper and flows were recorded using a 4" water meter and checked using a V notch stilling tank, in each location. Pump discharge was increased/decreased in accordance with the rate of dropping of the water levels. Pumping was carried out continuously for 2 weeks on all three wells. Pumping for one further week on the two wells furthest apart was continued in order to establish if there was an affect on the water levels when some wells were stopped pumping.

2.1.5 Monitoring of Private Wells

Three observation wells were especially drilled to help in monitoring the groundwater levels in the aquifer while pump testing was on-going. Also, there were six private wells in the region which were dipped daily throughout the test and for a few days afterwards. In effect, therefore, we monitored nine outside wells on a daily basis.

The results of this monitoring showed that there was no affect whatever on most of the observation wells. Indeed, the nearest private well which is just about 200m from the biggest production well, dropped by 2m, but stabilized quickly. It was, therefore, concluded that the test pumping, even for the extended period of 3 weeks, had virtually no effect on the aquifer.

2.1.6 Results of the Pump Testing

Pumping began on each well on the 7th October and ceased on different dates; 23rd October, 31st October and 1st November. By finishing each well test on a different date, it was possible to prove that the wells were independent. Stabilized flow rates of 31,000 gph, 23,000 gph and 21,000 gph were achieved giving a combined flow of 75,000 gph (340 m^3/hr). This was most encouraging as it more than met the water demand for the proposed scheme, even for the foreseeable future.

2.1.7 Chemical and Bacteriological Analysis

Samples were taken from each well on 4 dates during the pump testing. There results showed that the water was of excellent quality. Indeed no bacteria counts were recorded after the initial pumping. The water is hard water because it comes from the limestones with values ranging from 300 - 350 mg/l of $Ca\ CO_3$.

2.1.8 Repeat Pump Testing

Because of the dry winter of 1991/92, it was thought that the water table would be lower in the autumn of 1992 so a repeat pump test was organised and performed in September and October, 1992. The same procedure was carried out. Discharge was then reduced until stabilization occurred. This pump testing in 1992 proved that, not only were the very good results of the previous year correct, but if anything, were under estimated.

The following table gives a summary of the outputs and drawdown:-

Well Number	S.W.L. m	Draw Down/m	Yield m^3/hr	Yield gph	Yield gpd
Well 5A	3.29	7.13	165.6	36,400	874,400
Well 6A	2.81	4.15	114.6	25,200	604,800
Well 7A	3.47	9.03	102.6	22,500	540,000
					2,019,200

2.1.9 Aquifer Protection Survey

A detailed survey of the whole aquifer is now nearing completion. It is obviously vital to protect this large natural resource of high quality water. The Aquifer Protection Zones are being enforced via the Planning Process.

2.1.10 Monitoring of Water Levels

Water table levels are taken weekly on the three production wells and on the three especially drilled observation wells. A history of almost two years of ground water levels have now been logged in this aquifer.

Acknowledgements

I would like to thank the following who have generously helped me in my work with groudwater over the last few years:-

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E.P.S., Mallow

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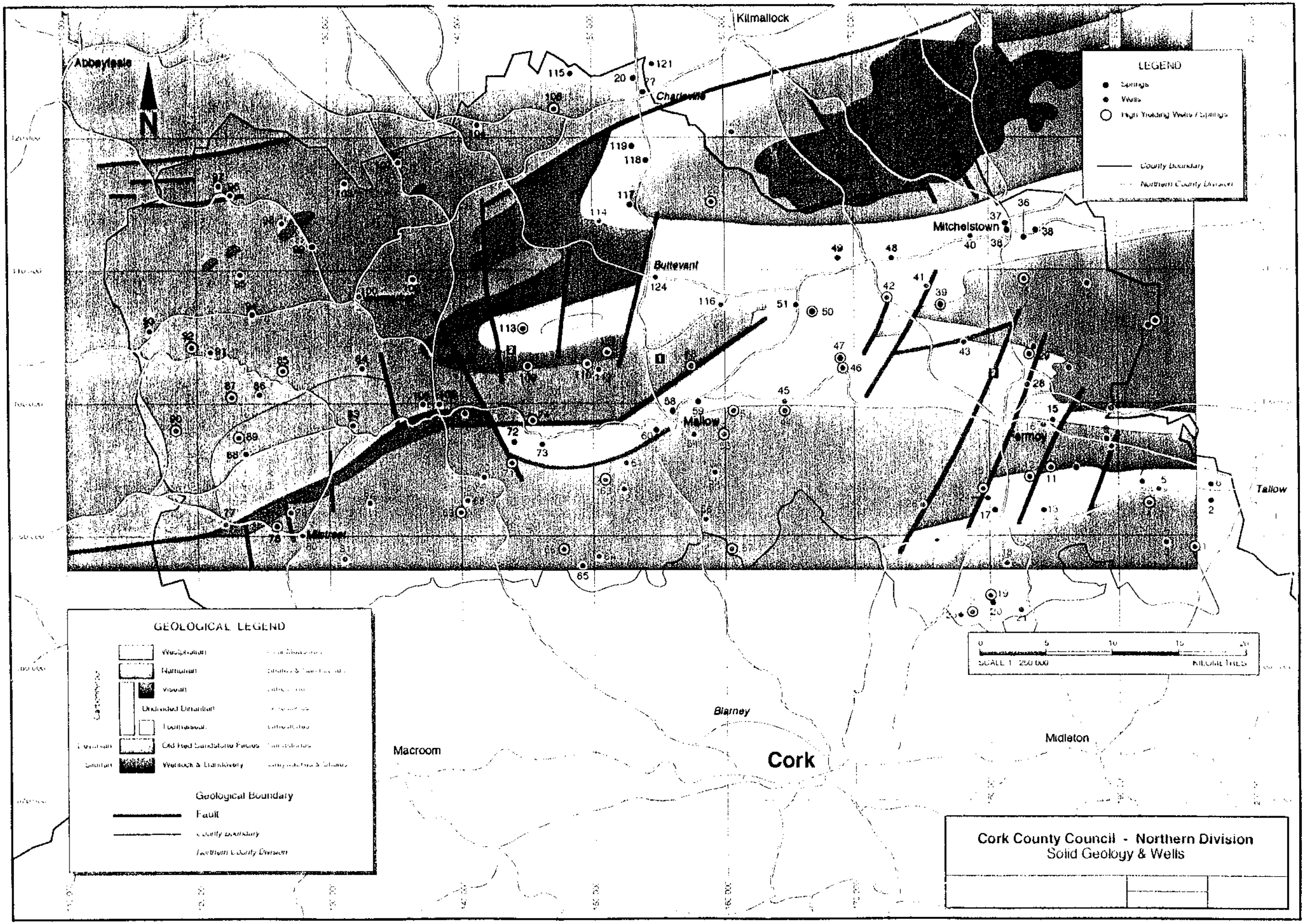
I would finally like to thank the A/County Engineer, Mr. C. B. Devlin for allowing me to present this paper.



Kilmallock
Abbeyfeale
N
Charleville
Buttevant
Mitchelstown
Mallow
Fermoy
Tallow
Blarney
Macroom
Cork
Midleton
LEGEND
Springs
Wells
High Yielding Wells / Springs
County Boundary
Northern County Division
GEOLOGICAL LEGEND
Westphalian
Namurian
Visean
Undivided Dinantian
Tournaisean
Old Red Sandstone Facies
Wenlock & Llandovery
Geological Boundary
Fault
County Boundary
Northern County Division
SCALE 1 : 250 000
KILOMETRES
Cork County Council - Northern Division
Solid Geology & Wells

<u>Review of Legislation Relating to the Quality of Groundwater</u>

P'laoise 1993

Owen C. Boyle

April, 1993

3. Local Government (Planning and Development) Acts, 1963 and 1990

A number of provisions in the Planning Acts can be used to protect groundwater. Every planning authority is required to make a development plan (Section 19) which must include objectives for preserving, improving and extending amenities in its area. In the Third Schedule to the Act it is stated that these objectives may provide for prohibiting, regulating or controlling the deposit or disposal of waste materials and refuse and the disposal of sewage. Presumably this includes situations where such deposit or disposal could endanger groundwater or at least groundwater sources of water supply. However, the Third Schedule goes on to state that the plan objectives may provide for prohibiting, regulating or controlling the pollution of rivers, lakes, ponds, gullies and the seashore. Groundwater is notable by its absence from this list.

Permission may be refused for development which conflicts with the proper planning and development of the area, regard being had to the provisions of the plan (Section 26).

The 1990 Act provides that no compensation is payable in respect of certain reasons for refusal or conditions attached to a planning permission. The reasons for refusal include situations where the proposed development would cause, inter alia, serious water pollution or pollution connected with the disposal of waste (paragraph 7) or would be prejudicial to public health [paragraph 8 (vii) of the Third Schedule to the 1990 Act].

Non-compensatable conditions that may be attached to a planning permission relate to prohibition, regulation or control of the deposit or disposal of waste materials and refuse, the disposal of sewage and the pollution of rivers, lakes, ponds, gullies and the seashore [paragraph 22 of the Fourth Schedule].

In assessing applications for planning permission for single dwelling houses, local authorities are guided by the recommendations for the construction and siting of septic tanks set out in Standard Recommendation 6, 1991 of the NSAI. They have been urged to have regard to S.R.6. 1991 in their implementation of the Planning Acts by Circular Letter PD 1/92 of 8th January 1992, which refers specifically to the fact that septic tank pollution is a health hazard and that there is increasing concern with the dangers of polluting groundwaters.

4. Building Regulations, 1991

Technical Guidance Document H, Drainage and Waste Disposal, has been published by the Minister for the Environment under Article 5 of the Building Regulations, 1991 for the purpose of providing guidance with regard to compliance with the requirements of Part H of the First Schedule to the Regulations.

The Guidance Document, in relation to septic tanks for single houses, refers to S.R.6.:1975, which has now been superceded by S.R.6:1991. For septic tanks serving more than one house, it refers to BS 6297:1983, Design and Installation of Small Sewage Treatment Works and Cesspools.

Where works are carried out in accordance with Guidance Document H, this will, prima facie, indicate compliance with the requirements of the Building Regulations.

5. Local Government (Water Pollution) Act, 1977

Section 1 of this Act defines "waters" as including aquifers and defined an "aquifer" as any stratum or combination of strata that stores or transmits sufficient water to serve as a source of water supply.

This definition of an aquifer has been changed in the 1990 Amendment Act (summarized below) to cover:

> "any stratum or combination of strata that stores or transmits water."

Obviously, therefore, any provision of the 1977 and 1990 Acts relating generally to waters also relates, in particular, to aquifers.

Section 3 states that a person shall not cause or permit any polluting matter to enter waters. This prohibition does not apply to, inter alia, discharges of trade or sewage effluents, provided these effluents are licensed under Section 4.

Section 4 prohibits the discharge of any trade or sewage effluent to waters except under and in accordance with a licence granted by the relevant local authority. Discharges from sewers (i.e. sewage discharges by a sanitary authority) are exempted from this licensing requirement. However, such discharges may now fall to be licensable by the EPA under Section 59 of the EPA Act.

A local authority may refuse to grant a licence under Section 4 or may grant the licence subject to such conditions as it thinks appropriate. In considering the grant or refusal of a licence the local authority would have to consider the need to protect aquifers from pollution.

A local authority may not grant a licence if the effluent concerned would not comply with, or would result in the waters to which the discharge is made not complying with, any relevant standard prescribed under Section 26 of the Act.

[See:
- Local Government (Water Pollution) Regulations, 1992
- Local Government (Water Pollution) Act, 1977, (Control of HCH and Mercury Discharges) Regulations, 1986,
- Local Government (Water Pollution) Act, 1977, (Control of Cadmium Discharges) Regulations, 1985.]

Section 12 of the Water Pollution Act empowers a local authority to serve a notice on any person having custody or control of polluting matter specifying the measures to be taken in order to prevent entry of such polluting matter to waters and the period within which such measures are to be taken.

Section 13, as substituted by Section 10 of the 1990 Amendment Act, provides that a local authority, for various purposes, such as to prevent pollution of waters in its area or to remove such polluting matter, may take such steps as it considers necessary to prevent such matter from entering waters, may mitigate the effects of any pollution caused and may recover the cost of such operations from the person responsible.

Section 14 requires the person responsible for an accidental discharge of polluting matter to waters to notify the local authority in the area as soon as possible.

Section 15 empowers a local authority to make a water quality management plan for any waters in its functional area. The plan shall contain objectives for the prevention and abatement of pollution of waters.

Section 22 requires a local authority to carry out or cause to be carried out such monitoring of waters and discharges to waters as it considers necessary for the performance of its functions.

Section 26 provides that the Minister may prescribe quality standards for waters, trade effluents and sewage effluents. Regulations under this section may relate, inter alia, to

- all or specified classes of waters
- waters in specified areas
- waters specified by reference to their use.

6. <u>Local Government (Water Pollution)(Amendment) Act, 1990.</u>

A number of provisions relating to penalties and enforcement procedures have been strengthened.

The major amendments which have a bearing on groundwater are as follows:

<u>Section 2</u> : The definition of aquifer has been extended to cover "any stratum or combination of strata that stores or transmits water".

<u>Section 21</u> allows a local authority to make bye-laws relating to all or a particular part of its functional area where the authority considers it necessary to do so in order to prevent or eliminate the pollution of waters. The

bye-laws may prohibit or regulate specified activities carried on for the purposes of agriculture, horticulture or forestry.

The Minister may also require a local authority to make such bye-laws where he believes them to be necessary.

Bye-laws under the section may be made in respect of activities such as the collection, storage and disposal of agricultural wastes, and the use of manure, fertilizers and pesticides.

Bye-laws may prohibit certain activities in particular areas, or regulate the manner in which they are conducted by subjecting them to conditions.

The making of bye-laws is, of course, a reserved function by virtue of the Management Acts.

7. Council Directive of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances (80/68/EEC).

The purpose of the Directive is:-

(a) To prevent the pollution of groundwater by substances in List I or List II.

(b) As far as possible to check or eliminate the consequences of pollution which has already occurred.

The definitions given in Article 1.2 include:-

Groundwater means all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.

Pollution means the discharge by man, directly or indirectly of substances or energy into groundwater, the results of which are such as to endanger human health or water supplies, harm living resources and the aquatic ecosystem or interfere with the legitimate uses of water.

Member States are required to:

(a) prevent the introduction into groundwater of substances in List I; and

(b) limit the introduction into groundwater of substances in List II so as to avoid pollution.

To comply with these obligations Member States are required to prohibit all direct discharges of List I substances. They may authorise any disposal of tipping for the purposes of disposal which might lead to indirect discharge of List I substances only after prior investigation, and provided that all necessary technical precautions necessary to prevent such discharge are observed.

Discharge of List I substances to groundwaters is allowed, however, if the groundwater is permanently unsuitable for other uses or if the discharge is due to re-injection of water into the same aquifer in certain limited circumstances. Artificial recharge of groundwater is also allowed.

With regard to List II substances, authorisation for direct discharge, or for tipping for the purpose of disposal which might lead to indirect discharge, is allowed only after prior investigation, and provided that all technical precautions for preventing groundwater pollution are observed.

8. Local Government (Water Pollution) Regulations, 1992

The provisions of Part VI of these Regulations deal with the control of discharges to aquifers. These provisions complement controls under other legislation, and, taken together, are intended to ensure full transposition into Irish law of relevant provisions of Council Directive 80/68/EEC, described above.

Further statutory provision remains to be made in regard to aspects of the Directive relating to tipping or landfill of waste containing List I or List II substances (i.e. authorization, etc).

The overall context in which these Regulations have been made and the main provisions of Part VI of the Regulations are worth reviewing.

The pollution control provisions of the Local Government (Water Pollution) Acts, 1977 and 1990 are fully applicable to water contained in an aquifer. Such water accordingly enjoys the protection afforded by the general prohibition on the entry of polluting matter to waters, the requirements in relation to the licensing of trade and sewage effluent discharges and the other pollution prevention provisions e.g. the issue of notices under section 12.

The 1977 and 1990 Acts, together with the procedures set out in associated Regulations, are generally adequate to ensure compliance with relevant provisions of Council Directive 80/68/EEC. These statutory controls are supplemented by the European Communities (Waste) Regulations, 1979 and the European Communities (Toxic and Dangerous Waste) Regulations, 1982, in the case of potential pollution of groundwater arising from activities involving the disposal or tipping for the purpose of disposal of those harmful substances.

Part VI of the 1992 Regulations introduces a number of additional requirements in respect of the licensing of trade and sewage effluents containing any of the harmful substances specified in the First or Second Schedules* where it is proposed to discharge such effluents to an aquifer.

These requirements build on the procedures contained in Part II of the 1978 Regulations on licence applications. They introduce specific obligations in relation to conducting prior investigations and the matters to be addressed in conditions attached to a licence, and provide for periodic reviews of such licences and monitoring for the purpose of determining compliance with licence conditions and the effects of a discharge on water in an aquifer.

Article 40 requires an applicant for a licence to carry out a prior investigation into specified matters relating to the aquifer to which it is proposed to make the discharge. The applicant is also required to make an assessment of the environmental impact of alternative methods of disposal of

* These substances are the same as those in Lists I and II in the Annex to Directive 80/68/EEC.

the harmful substance(s) concerned. The results must be submitted to the local authority with the licence application and the authority must take them into account in reaching its decision.

There is provision to dispense with the prior investigation requirement in a situation where the licence applicant can satisfy the authority that the harmful substance(s) in the effluent is present in such small a quantity and concentration as to obviate the danger of deterioration in the quality of the water in the aquifer concerned.

Article 41(1) establishes a quality standard of 0 (zero) milligrams per litre for the harmful substances specified in the First Schedule in the case of sewage effluent and trade effluent discharged to an aquifer. The effect of a zero standard is to prohibit such discharges; except in specific situations described below, a licence could not be granted for the discharge of effluent containing such substances.

A standard different from the quality standard prescribed in article 41(1) may, however, be specified in conditions attached to a licence for a discharge of trade effluent or sewage effluent to an aquifer where the results of the prior investigation furnished with the licence application show that the water in the aquifer concerned is permanently unsuitable for domestic, commercial, industrial, agricultural, fisheries or recreational uses, and where all practical technical precautions have been taken to prevent the entry of any of the harmful substances specified in the First Schedule to other (ground or surface) waters.

A different standard may also be specified in conditions attached to a licence where the discharge concerns the reinjection into the same aquifer of water used for geothermal purposes, water pumped out of mines and quarries or water pumped out for civil engineering works.

A quality standard of 0 (zero) milligrams per litre is prescribed for water in an aquifer in respect of the harmful substances specified in the First Schedule which might be caused or permitted to enter the water as a result of any disposal or tipping of the substances, or of any material containing them, or as a result of any activities on or in the ground. (Article 46).

A standard other than the quality standard of 0 (zero) milligrams per litre may be specified for a harmful substance in the Second Schedule in conditions attached to a licence for a discharge of sewage effluent or trade effluent to an aquifer provided that all practical technical precautions are observed to prevent the water in the aquifer being so affected by the harmful substance as to endanger human health or water supplies, harm living resources and the aquatic ecosystem or interfere with the beneficial use of the water (article 42).

Sub-article 42 (2) requires local authorities to take such steps as may be appropriate to secure compliance with the prescribed quality standard for water in an aquifer. Statutory provisions which may be relevant in this regard are sections 3, 10, 11, 12, 13 and 23 of the Water Pollution Act, 1977, as amended by the Water Pollution (Amendment) Act, 1990 and section 21 of the 1990 Act.

Authorities should also use, as appropriate, the controls in the European Communities (Toxic and Dangerous Waste) Regulations, 1982, to ensure compliance with the quality standard prescribed in article 46.

9. The E.C. (Waste) Regulations 1979, and The E.C. (Toxic and Dangerous Waste) Regulations, 1982

These two sets of Regulations transpose into Irish law the provisions of:

(1) Directive 75/442/EEC on waste, and

(2) Directive 78/319/EEC on toxic and dangerous waste.

They provide for control of the storage, treatment, transport and deposit of waste. They make local authorities responsible for the planning, organisation, authorisation and supervision of disposal of waste in their areas. They include arrangements for the issue by the local authorities of permits for storage, treatment or deposit of waste and for the preparation by them of general waste and toxic and dangerous waste plans.

10. **E.C. (Environmental Impact Assessment) Regulations, 1989, and Local Government (Planning and Development) Regulations, 1990**

These two sets of Regulations provide for the incorporation into Irish law of the provisions of Council Directive 85/337/EEC (on the assessment of the effects of certain public and private projects on the environment) for relevant development other than motorways.

The EIA Directive and these Regulations give effect to Community policy for prevention of pollution at source, and ensure that the effects of development on the environment are taken into account at the earliest possible stage in the planning and decision-making process. They require that relevant projects which are likely to have significant effects on the environment be subjected to an assessment of such effects (that is, to environmental impact assessment) before development consent is given to them. They provide for participation by the public in the decision making process, by giving them the opportunity to express their opinions and by requiring that their opinions be taken into account.

The developments (other than motorways) which must be subjected to EIA in Ireland are specified in the First Schedule to the 1989 Regulations. The EIA process in respect of these developments must, of course, include assessment of potential effects on groundwater, where appropriate.

Of particular interest for the protection of groundwater, however, are the following three types of development included in the First Schedule:-

Part I, 9	-	A waste disposal installation for the incineration or chemical treatment of hazardous waste, or the filling of land with such waste.
Part II, 2 (b)	-	Drilling for water supplies where the expected supply would exceed 5,000 cubic metres per day.
Part II, 11 (c)	-	Installation for the disposal of industrial and domestic waste with an

annual intake greater than 25,000 tonnes.

11. <u>Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources.</u>

The Directive reflects concern about the high levels of nitrates in waters in many parts of the Community. It covers surface freshwaters, estuarine and coastal water and groundwater.

The Directive requires Member States to:

(a) establish codes of good agricultural practice by 19 December, 1993, for the purpose of providing a general level of protection for all waters against pollution by nitrates. Codes must contain at least the items in section A, Annex II (Article 4). The Department of Environment and the Department of Agriculture Food and Forestry are preparing a code of good practice at present;

(b) identify waters affected by pollution or which could be so affected in the absence of action programmes to reduce nitrate losses from agriculture (Article 3.1);

(c) designate as vulnerable zones all known areas of land which drain into waters identified at (b) above and which contribute to pollution. Designations are to be made in the first instances by 19 December, 1993 (Article 3.2) with the position to be reviewed at least every four years (Article 3.2 and 3.4), and

(d) establish action programmes in respect of designated vulnerable zones within two years of the initial designation and within one year of each additional designation. The programmes, which are intended to achieve significant reductions in nitrates losses to waters, must include measures contained in Annex III. In addition, any elements of the code of good agricultural practice which have not been superceded by measures listed in Annex III must be included. Action programmes must be implemented within four years of their establishment (Article 5).

A monitoring programme to determine the nitrate concentration in surface freshwater and in groundwater and to identify waters at (b) above and areas of land requiring designation as at (c) above must, therefore, be put in place by local authorities.

The Directive is targeted at combating water pollution caused by nitrates in livestock manure, chemical fertiliser, residues from fish farms, sewage sludge and other substances containing a nitrogen compound, which are applied to land to enhance the growth of vegetation in the pursuit of agriculture. "Fertiliser" is intended to embrace these sources and any other potential sources of a "nitrogen compound" which is used on land for that purpose. These pollution sources would be diffuse in nature.

Other, point, sources could include defective farm effluent or waste storage facilities, problems due to the failure to segregate and deal properly with rainwater and soiled water from farmyards and other contaminated open areas, inadequate arrangements to collect and dispose of parlour washings, etc. Such sources of pollution, of course, are not acceptable and are controllable under the Water Pollution Acts.

12. <u>E.C. (Use of Sewage Sludge in Agriculture) Regulations, 1991.</u>

These Regulations give formal effect in Irish law to Council Directive 86/278/EEC of 12 June, 1986.

The purpose of the Regulations is to control the use of sewage sludge in agriculture in such a way as to prevent harmful affects on soil, vegetation, animals and man.

They make local authorities responsible for the supervision of the supply and use of sewage sludge in agriculture.

Only treated sewage sludge, as defined in the Regulations, may be used in agriculture, except where it is injected or otherwise worked into the soil. The Regulations set out the restrictions and conditions applying to the use of sludge in agriculture. These include the requirement to ensure that the quality of surface water and groundwater is not impaired. Advice on how water quality can be protected is given to local authorities in Circular Letter L8/91 of 12 July 1991 which was issued with the Regulations.

The Regulations fix the maximum allowable concentrations of heavy metals in both the receiving soil and sewage sludge used for agricultural purposes. They also fix the maximum amount of sludge which may be applied to soil at 2 tonnes dry matter per hectare per year.

13. EC (Quality of Water Intended for Human Consumption) Regulations, 1988.

These Regulations give formal effect in Irish law to E.C. Directive 80/778/EEC of 15 July, 1980. They apply to all water intended for human consumption whether it is used in its original state or after treatment, and cover all water, other than natural mineral water, whether

(a) supplied for consumption, or

(b) used in food production and affecting the wholesomeness of the foodstuff.

The Regulations lay down national quality standards for water intended for human consumption based on the recommendations of the Technical Committee on Effluent and Water Quality Standards.

The standards cover organoleptic, physico-chemical and microbiological parameters, including toxic substances.

In many cases water from private boreholes serving small numbers of houses receive no treatment, and, even in the case of major public groundwater supplies no treatment may be necessary other than disinfection.

These standards, therefore, are of considerable significance for water quality control in aquifers which are, or have the potential to be, used as sources of water supply.

14. Environment Protection Agency Act, 1992

The new Agency has wide ranging functions and powers relating to environmental control generally, including protection of the quality of groundwater. The functions of the Agency include:-

(a) the licensing, regulation and control of activities for the purposes of environmental protection,

(b) the monitoring of the quality of the environment, including the establishment and maintenance of data bases of information related to the environment and making arrangements for the dissemination of such information and for public access thereto,

(c) the provision of support and advisory services for the purposes of environmental protection to local authorities and other public authorities in relation to the performance of any function of those authorities,

(d) the promotion and co-ordination of environmental research, the provision of assistance and advice in relation to such research and the carrying out, causing to be carried out, or arranging for, such research. [Section 52]

The following provisions of the EPA Act are of relevance to protection of groundwater quality:

- The Agency is required to specify and publish criteria and procedures for the selection, management, operation and termination of use of landfill sites. [Section 62].

- The Agency is given strong supervisory powers over the functions of local authorities relating to environmental protection, including powers to request reports, to direct the local authority to carry out a function and, where necessary, to carry out the function itself and recover the costs from the local authority [Section 63].

- There is provision for the establishment and maintenance by the EPA of a database on environmental quality. Groundwater is specifically mentioned in this regard [Section 69].

- The duty is placed on the Agency to prepare and publish State of the Environment reports every five years [Section 71].

- The Agency must specify and publish environmental quality objectives [Section 75].

- The Agency is empowered to prepare and publish codes of practice, approve of a code of practice drawn up by any other body or withdraw such approval [Section 76].

The First Schedule to the EPA Act lists the activities which require a licence issued by the EPA. It is intended that licences issued by the EPA will be integrated, covering emissions to air, water and soil, waste disposal, noise control, etc..

15. <u>Proposal for a Council Directive on the landfill of waste (91/C190/01)</u>

This proposal covers landfill for:

- hazardous waste

- municipal and non-hazardous and other compatible wastes

- inert waste.

Its major provisions relate to:

- application for a landfill permit,

- conditions and content of a permit,

- the types of wastes not acceptable in a landfill,

- waste acceptance procedures,

- control procedures in operation and aftercare phases,

- closure procedure,

- civil liability of operator,

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- waste acceptance procedures,

- control procedures in operation and aftercare phases,

- closure procedure,

- civil liability of operator,

- operation of existing landfill sites,

- financial guarantee by the operator to cover costs of closure,

- establishment of a landfill aftercare fund.

Comprehensive technical requirements for landfill are set out in four Annexes to the Directive.

Annex 1 lays down the general requirements for landfill sites, including:

- location,

- fencing and landscaping,

- control of access and operation,

- water control and leachate management,

- protection of soil and groundwater,

- gas control,

- prevention of nuisances, etc.

Annex II is concerned with the basic information to be provided to the competent authority in the case of:

A. The establishment and operation of a landfill.

B. The conditioning plan of an existing site.

C. The closing of a landfill.

Annex III sets out the criteria and procedures for acceptance of waste at landfills, including characterization of wastes, sampling, control procedures, leachate monitoring, loading rates, etc.

Annex IV describes a minimum programme of control procedures in the operation and after-care phases. It is of interest that after-care is envisaged as continuing for at least 30 years after closure of the site.

16. Waste Bill

A comprehensive bill is in preparation which will deal with the collection, storage, treatment, tipping and recycling of waste and which will provide for the transposition into Irish law of the proposed Council Directive on the landfill of waste, when adopted.

17. Further Direction of Community Policy on Groundwater.

At a Ministerial Seminar on groundwater held at The Hague in November 1991, the participants recognized that:

* groundwater is a natural resource with both ecological and economic value, which is of vital importance for sustaining life, health, agriculture and the integrity of ecosystems;

* groundwater resources are limited and should therefore be managed and protected on a sustainable basis;

* it is essential to protect groundwater resources against overexploitation, adverse changes in hydrological systems resulting from human activities, and pollution, many forms of which can produce irreversible damage.

The participants also noted and described the many threats to groundwater resources which endanger drinking water supply, agriculture and other legitimate uses of groundwater and the diversity of groundwater dependent ecosystems throughout the Community.

It was recognized that existing Community legislation was inadequate to protect this essential resource and the participants agreed:

* to preserve the quality of uncontaminated groundwater;

* to prevent further deterioration of contaminated groundwater;

* to restore, where appropriate, contaminated

groundwater and soil to a quality required for drinking water production purposes and for the ecosystem taking into account local conditions;

* to prevent long-term overexploitation, continuous lowering of the groundwater table and groundwater pollution through various routes, in particular with the aim of avoiding deterioration or impoverishment of ecosystems;

* to replenish, where appropriate, the groundwater system to a sustainable level.

The objective of sustainability should be implemented through an Integrated Approach, which means:

* that surface water and groundwater should be managed as a whole paying equal attention to both quantity and quality aspects;

* that all interaction with soil and atmosphere should be duly taken into account;

* that water management policies should be integrated within the wider environmental framework as well as with other policies dealing with human activities such as agriculture, industry, energy, transport and tourism.

The participants agreed to establish a programme of actions to be implemented by the year 2000 at national and Community level aiming at sustainable management and protection of freshwater resources, and invited the European Commission to elaborate the necessary proposals to implement the recommended Action Programme. Twenty two separate actions were proposed for inclusion in the programme. The proposals would set a framework for Member States to implement national programmes.

A Council Resolution of February 1992 on the future of Community groundwater policy called upon the Commission:

- to submit a detailed action programme for which the conclusions of the Ministerial Seminar may provide guidelines, and

- to draft a proposal for revising Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances by incorporating it into a general freshwater management policy, including freshwater protection.

The Commission is in the process of preparing the necessary proposals. These are awaited and may be tabled in 1994 for Council consideration.

Review of Legislation Relating to the Quality of Groundwater

SUMMARY

While legislation relating to the use, development and quality of groundwater goes back to the last century, this paper deals mainly with more recent legislation relating to water quality. It includes discussion of the following:

- Local Government (Water Pollution) Acts, 1977 and 1990.
- Local Government (Water Pollution) Regulations, 1992
- EC (Environmental Impact Assessment) Regulations, 1989.
- Local Government (Planning and Development) Regulations, 1990.
- Council Directive 80/68/EEC on protection of groundwater against pollution caused by dangerous substances.
- Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources.
- Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment.

21/IV/193

Black List and Grey List Substances (List I and List II) Control in Relation to Groundwater - Current Status and Impending Changes.

Introduction.

The original concept of a black and grey list of substances whose concentration in and discharge to waters needed to be urgently controlled derived from the US EPA.

In the EEC, the debate for such control had commenced in the late 60's and gained momentum when the Marketing and Use Directive was ratified in 1967.

The Directive which set up the Black and Grey List (formally known as List I and List II) was finally passed on 4 May 1976 as 76/464/EC entitled On Pollution Caused by Certain Dangerous Substances Discharged into the Aquatic Environment.

The preamble to the Directive clearly links it with other then Draft and formal Conventions i.e.

- The Convention on the Prevention of Marine Pollution.
- Convention on the Protection of the Rhine.
- Convention on the Protection of International Watercourses and Marine Environment.

and also emphasised the need to coordinate the controls used.

The Directive was empowered under Article 100 of the Treaty of Rome which relates to equalising competition across the Community, and to implement more extensive Community rules also invoked Article 235 of the Treaty to this effect.

This Directive was one of the bulkwarks of the First and Second Action Programme on the Environment in the EEC.

Structure of the Directive.

The Directive established a framework for developing a first list - List I of substances based on the criteria of

- toxicity
- persistence
- bioaccumulation
- carcinogenicity through the aquatic medium

and stipulated that;

- pollution from List I substances should be eliminated.
- limit values and water quality objective values for these substances would be established.
- reference methods of measurement and detection limits would be specified.
- reference monitoring procedures would be specified.
- BAT must be applied to treat all List I substances prior to discharge and they should be eliminated from the manufacturing cycle wherever possible.

The second List of substances - List II consisted of literally everything else, which can have a 'deleterious effect on the aquatic environment. List II substances must be controlled by;

- Member States establishing water quality objectives for these substances and determining emission values on that basis.
- all discharges should be subject to licencing.
- programmes for reduction of pollution by List II substances were to be established.
- EC was to harmonise the approach in all the Member States.

Also in addition to the specifications of the Directive, two catch all clauses were added.

1. That no action taken on foot of this Directive should increase the level of pollution in waters and

2. That Member States were to prohibit all acts which intentionally or unintentionally circumvent the provisions of the Directive.

Outline of List I and List II.

The Annex to the Directive (appended) outlined the general groups of substances which it was felt would fall into the List I and List II categories.

It is important to note that **legally** a substance **only** becomes a List I substances when the Council of the EC declare emission values and water quality objectives for that substance and not before.

This subsequently became a near fatal flaw in progressing the implementation of the Directive.

Establishing List I.

To declare a substance to be a List I material the Commission firstly had to carry out a series of studies. It was obliged to carry out;

- Technical and economic studies on the use of the substance.
- Ecological studies on the impact.
- Studies on control technology.

It then had to seek the opinion of the ECO Toxicological Committee and National Expert Group to determine limit values and water quality objectives and finally get unanimous agreement with all Member States on these values before declaring the substance List I.

One major difficulty was that the U.K. had insisted on using the EQO approach rather than emission values based on varying water quality related uses and objectives.

By 1992, progress on the Directive was seriously bogged down and many involved at National Expert level recognised that many flaws in the mechanism existed.

A short list of 129 specific substances was drawn up (appended) based on studies completed or in progress to that date and this is the List which is still being addressed 11 years later.

The mechanisms used to arrive at this priority List is described below in a precis of a communication from the Commission to the Council on 22 June, 1982.

Directive 76/464 EEC is a framework Directive which must be implemented by means of subsidiary Directives in respect of substances contained in List I.

These subsidiary Directives mainly concern direct industrial discharges into the aquatic environment. However, in certain cases it will be necessary to devise a comprehensive approach in order to eliminate pollution cause by certain substances discharged into the different environments (water, air, soil) or by indirect or diffuse discharges.

Choice so far of priority List I Substances.

With the exception of mercury and cadmium, List I in the Annex to the Directive of 4 May, 1976 referred to above does not mention individual substances, but families or groups of substances (for example, organohalogen compounds, etc).

It is therefore necessary to choose certain individual substances from among the families of groups in order to study them and, if appropriate, prepare proposals for the Council. The Directive states that these substances must be selected mainly on the basis of their toxicity, persistence and bioaccumulation.

Following the adoption of the Directive on 4 May, 1976, the Services of the Commission began the choice of individual priority substances from List I. In this it was helped by a group of National Experts.

During these meetings four series of substances have been chosen. These have be been studied by the services of the Commission, and several were the subject of proposals to the Council which have been, or are being, prepared. List I also includes carcinogens, some of which are also being examined by the services of the Commission. The substances selected and the progress of the work on them are shown in Table 1 (appended).

Studies Carried out and Method Pursued in Drawing up a List of Substances.

In parallel with the work of choosing certain priority substances for List I, the Commission has effected a series of studies in order to establish a complete list of substances which might be in List I.

There are about four million chemical compounds of which about 50,000 are used for technical purposes. The aim of the initial study was to identify those among the substances used for technical purposes which, by virtue of their chemical structure, belong to the families and groups of List I.

1, 500 substances have been identified.

It quickly became clear that the majority of these substances are not produced or converted on a regular basis within the Community, or that this only occurs in very small quantities (from a few kilograms to a few tonnes per year).

Closer analysis has shown that of these 1,500 substances, 1,000 are produced or used in quantities of less than 100 t/yr, 186 more than 1,000 t/yr, 44 more than 10,000 t/yr and only 25 in excess of 100,000 t/yr.

Finally, in a third phase, 500 substances produced or used in quantities greater than 100 tonnes per year within the Community have been examined by means of a mathematical model to evaluate the risks to the aquatic environment from discharges of these substances.

This examination has enabled a classification of substances in order of priority in relation to the risk each constitutes for the aquatic environment and human health. (SRI Algorithm Report).

However, the mathematical model can only perform a rough simulation of the natural environment. It has also been necessary to make a number of estimates owing to the lack of exact data on the quantities, toxicity, persistence and bioaccumulation of certain substances.

Several other lists of substances presenting risks to the aquatic environment were also taken into account in this work;

The U.S EPA list of toxic pollutants -list of hazardous substances, the Canadian list of priority chemicals 1979 - the German catalogue of substances constituting a risk to the aqueous environment.

Furthermore, the International Commission for the Protection of the Rhine against Pollution drew up a list of dangerous substances for that watercourse. The Services of the Commission participated in this work.

The Services of the Commission have drawn up a provisional list of 122 substances on the basis of the various lists of substances and on the studies referred to above. This list was to the Member States with a view to obtaining additional information on, in particular, the quantities produced, consumed and discharged in the aquatic environment by each Member State.

This additional information was examined at a meeting of national experts, thus enabling a list of 108 substances out of 122 to be drawn up.

Since the 108 substances selected could not be examined simultaneously, it was agreed at this meeting to choose 15 substances to be studied first.

When one adds to this list of 108 substances the 21 substances which were chosen earlier and which have already been studied (see Table 1) one obtains the complete list of 129 substances.

List of Substances.

Within this list it is necessary to distinguish four categories of substances in relation to the progress made in the work;

1. Seven substances, indicted by *** are already the subject of a proposal or a communication to the Council.

2. 14 substances indicated by **, are under study or have been studies.

3. 15 substances, indicted by *, will be studied in the near future.

4. 93 substances will be studied subsequently.

The Commission does not consider this list to be final and exhaustive. It plans to review it, if appropriate, in the light of new scientific knowledge and to take account of any other substances which might be produced or used in future.

It considers further that these substances **SHOULD** be included in List I of Council Directive 76/464/EEC. Where this has not already been done, these substances will be studied as a matter of priority and the Commission will submit to the Council, where necessary, appropriate proposals for the elimination of the pollution of the aquatic environment caused by these substances.

It can be clearly seen from the above that the Commissions clear intention was to have all 129 substances declared as List I. However, not all Member States agree with the totality of the List.

Major hold ups due to National sensitivities occurred, in particular with the "Drins", but a minor breakthrough was achieved in 1986 with the development of a standardised 'daughter' Directive 86/280/EEC which can be used as a template for further Directives.

However, only 17 of the 129 substances have been dealt with to date and these are covered by the following 'daughter Directives'.

Mercury - 82/176/EEC and 84/156/EEC
Cadmium - 85/513/EEC
Hexachlorocyclohexane - 84/491/EEC
DDT - 86/280/EEC
Carbon tetrachloride - 86/280/EEC
Pentachlorophenol - 86/280/EEC
"The Drins" - 88/347/EEC
Hexachlorobenzene - 88/347/EEC
Hexachlorobutadiene - 88/347/EEC
Chloroform - 88/347/EEC
1,2 Dichloroethane - 90/415/EEC
Trichloroethane - 90/415/EEC
Trichloroethane - 90/415/EEC
Perchloroethane - 90/415/EEC
Trichlorobenzene - 90/415/EEC

Some of these Daughter Directives have been implemented in Ireland by specific measures, Statutory Instrument S.I. 294 of 1985 on Cadmium and S.,I. 55 of 1986 on HCH and Mercury.

A regulation to implement 86/280/EC is being currently studied but many of the other substances are not currently licenced for discharge to Waters in Ireland..

Ultimately, it is probable that SI's will have to be issued to implement all aspects of the daughter Directives.

Actions on List II Substances.

Art. 7. of 76/464/EC obliges Member States to formulate National water quality objectives for all List II compounds and to initiate national reduction programmes. The National Technical Advisory Committee on Water Quality Standards set up by the Dept. of Environment had commenced this work in the 70's and produced Technical Memorandum No. 1. and No. 2. which produced some water quality standard guidelines. Other than the water quality objectives specified in other aquatic Directives no further elaboration of national guidelines has occurred. It should be noted that the EPA Act confers similar powers to that Agency to produce such guidelines and it is not clear as to who may ultimately produce them.

List I/List II and Groundwater.

Art. 4. of 76/464/EC directly applied the controls of List I and List II substances to groundwater which is quoted in toto hereunder.

Article 4.

1. Member States shall apply a system of zero-emission to discharges into ground water of substances within List I.

2. Member States shall apply to ground water the provisions of this Directive relating to the substances belonging to the families and groups of substances in List II, hereinafter called 'substances within List II'.

3. Paragraphs 1 and 2 shall apply neither to domestic effluents nor to discharges injected into deep, saline and unusable strata.

4. The provisions of this Directive relating to ground water shall no longer apply upon the implementation of a separate Directive on groundwater.

The important point to note is that this Article ceases to have effect after 80/68/EEC came into being. This Directive on the protection of groundwater against pollution by certain dangerous substances, expanded on the provision of Art. 4. of "464", but also point out that until 80/68/EEC was implemented in the Member State that Art. 4. still prevailed. Implementation of 80/68/EEC in Ireland was not completed until 11 years later when S.I. 271 of 1992 was brought into force in 1st Nov. 1992.

Control of Discharges to Aquifer under S.I. 271 of 1992 (Part IV).

The following is a short summary of the provisions of the S.I. in relation to List I and List II substances.

General.

Unfortunately, the S.I. does not exactly match the provisions of the Directive and indeed poses some interesting legal difficulties in complying with the terms specified.

Art. 39.

The definition section does not interlink or relate the regulation to 76/464/EC defined Lists I and II and only defines the harmful substances controlled under First Schedule and Second Schedule.

This is very significant as List I substances as mentioned in all Directives have a specific legal meaning which relates to whether they have had emission values and EQO's specified at Community level and reference measurement methods and detection limits. Furthermore, this definition section omits defining 'direct' and 'indirect' discharges as stipulated in the Directive.

Art. 40 (2).

A detailed schedule of what constitutes 'prior investigation' is specified which is required with every relevant licence application. A 9 point agenda of aquifer investigation is specified, which is possibly in some cases and probably in others beyond the legal result of a applicant to achieve i.e.

- access to land for overburden trials.
- pump tests.
- water quality determination etc.

All of which the regulations assume the applicant is empowered to carry out. The obligation for prior investigation as specified to this level of detail would require powers of access to land, wayleaves, which may not be possible for a private individual to obtain.

Art. 41 (1).

The concept of a zero discharge standard for those substances in fraught with difficulties given the failure to define "discharges" in Art. 39 in accordance with Art. 1 of the Directive and may lead to particular difficulties for group scheme septic tanks, isolated sewage disposal to percolation areas from factories, golf clubs etc. which were not intended to be regarded as direct discharges under the terms of the Directive. Such confusion has already occurred with some Local Authorities issuing Section 4 licences to discharges to percolation areas and peat bed units.

Again it must be emphasised that legally the Directive specified that Member States (Art 4 (1))

- shall prohibit all direct discharge of substances in List 1.

Which is not the same as the First Schedule of S.I. 271 which includes a plethora of substances which cannot be analytically defined.

Art. 42.

Unfortunately, the same criticism of imprecision can be levelled here as in Art. 41 in that it is legally and analytically impossible to exhaustively specify that the spectrum of substances alluded to in the Second Schedule has been examined.

Art. 46. (I).

This Article is worded strangely and implies that the EQO for the range of substances in the First Schedule should be zero in an aquifer upon which it is planned to locate a disposal facility, tailings down etc. or carry out any activity which might release any such substance.

This implies that one is obliged to find such an ultra pure aquifer and then proceed to locate a facility on it!!. Again, the analytical imprecision of defining the substances in the First Schedule rears its head.

Specification of the First and Second Schedules.

It seems that in proposing the Statutory Instrument it was chosen to ignore the preamble to the Annex in the Directive 80/68/EEC, which point out that eventual List I compounds will be recruited from this List and does not seek to ban all of the group of substances.

This is not because it may be permissible to pollute an aquifer with some organohalogens, for example, but merely because of the difficulty in defining a catch-all parameter, and the necessity to define reference methods of analysis detection limits etc.

In summary, it can be said of S.I. 271 of 1992 insofar as it implements the control of List I and List II substances that it fails to define what is a direct discharge to aquifers as specified in 80/68/EEC and also fails to mention Lists I & II which have specific legal meanings.

Are there any real List I/List II issues for Groundwater in Ireland?

Direct Discharges.

If we assume that the meaning of a direct discharge to groundwater is as defined in 80/68/EC

> 'the introduction into groundwater of substances in List I & II without percolation through the ground or subsoil'

then it is highly unlikely that many issues in relation to licensable discharges will occur. It would remain to be clarified if artificially created 'ground' or 'subsoil' as in constructed percolation areas would be deemed exempt as thus would have a particular bearing on all non-sewered developments other than single dwellings.

The provisions of S.I. 271 of 1992 in respect of re-injected waters are sensible in that Art. 41 (2) (b) enables the Licencing authority to consider all of the relevant issues before stipulating licence conditions. One would hope, however, that such conditions would relate to either specific substances or groups of substances which were:

(a) relevant to the application and
(b) analytically well defined and feasible detection limits were specified

Indirect Discharges.

Landfills.

In this case the issues and mechanisms of control are far from clear. In relation to private landfill operations control of most List I substances can be effected by:

- S.I. 271 of 1992 (Art. 46(I) & (II)).
- Water Pollution Act 1976 - Section 12.
- S.I. 33 of 1981 Toxic and Dangerous Waste Regulations.

The same criteria apply to Local Authority operated landfills.

However, the proposed Landfill Directive will operate to different criteria. The proposal in summary will categorise wastes on the basis of leachate quality which will determine the types of landfill to which they can be sent. The landfill will be classified essentially on the infiltration rate or leachate capture without complete regard to the totality of List I and List II or the current First/Second Schedules. This may lead to confusion as to what wastes are acceptable in some landfills.

The overall point would be that as yet there is no harmonisation between the codification of the Waste Directives, Landfill Directives and the current Schedules or Lists I and II.

Furthermore, the current environmental regulations are not conducive to the concept of Best Practicable Environmental Option (BPEO) which necessarly arises from the proposed Integrated Pollution and Control Licencing Directive and the similar provisions in the 1992 EPA Act.

The Extractive Industry.

Next to landfill operations the extractive sector offers the highest potential for impact in respect of metallic compounds round water and other related substances. Specific control is afforded by Section 12 of the Water Pollution Act and now by Art. 41 (2) (b) and Art. 46 of the new regulations.

Whereas, the situation for the List II type metals and metalliods is clear, i.e. that water quality objectives from the Directives S.I. 81 of 1988 (S.I. 293 of 1988 and 294 of 1989) can be applied to the aquifer and thereby a control strategy stated or adopted. The zero limit for First Schedule substances may prove problematic in some aquifers where detectable background values exist.

Since there was no such requirement for a zero EQO value, stipulated in the Directive, which concerns itself with the standards of the contaminant discharge and not the aquifer, it might have been more appropriate to use a phrase such as

> 'shall not raise the background values of'

or similar wording.

Agricultural Sector.

Generally, this sector can give rise to List II contamination mainly from substances which can cause taste/odour problems but also indirectly mobilise metals and metalloids. CCF fertilisers can contain cadmium as a significant contaminant depending on the rock phosphate source and this can give rise to contamination where direct ingress to ground waters can occur.

A similar observation can be made on the prioritised substances for inclusion in List I most of which are pesticides used in agriculture and horticulture. While instances of serious contamination are rare in Ireland they have occurred elsewhere, again associated with shallow or light soil profiles. In particular, substances with poor soil adsorption properties are prone to migration.

Industry.

Contamination of groundwater from underground services and tank leaks are a constant threat from a broad spectrum of activities and substances.

Most usually this relates to simple organic substances which elevate the background TOC values but it can also be from solvents, acids and alkalis all of which can pose a threat to secondary mobilisation of metals. Contamination by solvent leakage can be serious. Virtually, all manufacturing companies in the fine chemical sector now operate on or are putting in place groundwater monitoring programmes as are a slowly increasing number of companies in other sectors.

Local Authorities have increasingly stipulated groundwater monitoring in discharge licences. The Authorities are empowered to specify relevant action although the absence of National Guidelines of the Dutch VPR type can make the end target or prioritisation of tasks more subjective than is desirable.

Domestic Discharges.

Although domestic discharges from isolated dwellings are excluded from direct discharge licencing control, they can in practice impact on groundwater by discharging List I or List II compounds.

In terms of List I/List II degradation of locally contaminated groundwaters these discharges coupled with agricultural wastes still represent in practice the biggest problem area in Ireland.

The Future for 76/464/EC (List I and List II) Controls.

The implementation of this Directive and progress made in addressing the List of candidate substances has been painfully slow (17 substances in 17 years) which implies 129 years to get through the Commissions initial list.

As a mechanism for pollution control it was a victim of the unanimous agreement requirement under Art. 100 of the Treaty of Rome which may now disappear if the Maastrict Treaty is ratified. This will enable qualified majority decisions to be reached.

Furthermore, it was flawed in that it sought to address single substances from point source discharges whereas most of the impacts derived from the use of compounds.

Frustration has been widespread and since the earliest times Ireland has been vociferous in appealing for a more rational sectoral or harmonised approach.

In parallel to these single substance controls other environmental measures have gradually gained momentum such as the Paris Commission recommendations on BAT in various industrial sectors all of which serve to resolve the arisals of List I and List II pollutants at source or (as under the Marketting and Use Directives) at their end point use.

Revisions to 76/464/EC.

The Commission in 1990 announced a major revision to the way in which List I substances will be chosen. A joint programme between the EC and the Dutch Ministry for the Environment (VROM) will produce a new "Template" of criteria against which all substances can be judged. The template will include the old criteria of;

- toxicity, carcinogenuinty, bioaccumulation and persistence

but will also include production volumes, empirical concentrations in the environment, escapability and others.

This new mechanism will be presented to the next major North Sea Conference in 1995.

Integrated Pollution Prevention and Control Directive.

This proposed Directive is another nail in the coffin of the old List I and List II approach. This was clearly indicated in the explanatory memorandum which accompanied the penultimate draft of the Directive.

This Directive highlights;

Increased interest in, and recognition of, the advantages of bringing together, rather than fragmenting, the many efforts being made to improve our environment.

Objectives of Integrated Pollution Prevention and Control.

The main objectives of IPC are:

a) to prevent or solve pollution problems rather than transferring them to other parts of the environment

b) make pollution controls more efficient for industry and effective for the environment

c) increase ability to set priorities

d) encourage consistency in environmental law

This may involve repealing some existing Directives and Regulations which place exclusive emphasis on one media only.

In relation to List I and List II controls and related waste management control the Commission in the IPC Directive comment as follows:

> "There are also a number of water Directives. The most notable is Directive 76/464/EEC on the discharge of dangerous substances into the aquatic environment. This will not be repealed as there will be processes discharging such substances into water which are not covered by IPC, for which future proposals may be necessary. However, the processes covered by the current daughter Directives to 76/464 are all covered by the list of processes in Annex I to the IPC Directive. It is proposed therefore that all such plant, listed in Annex II must receive an integrated permit, and that only the quality standards and emission limits set in the daughter Directives will continue to apply to these processes. All other provisions, such as the review procedure, would henceforth be governed by the IPC Directive. The future need for these daughter Directives will therefore also be reviewed once IPC is established. Waste management installations governed by the IPC Directive and Directives 91/156/EEC or 91/689/EEC would need to incorporate both sets of requirements of the Directives into the permitting procedure.

Conclusion.

It can be seen that (luckily) there is no bright future for the ridiculously slow process of controlling emissions of dangerous substances by single substance regulation a la 76/464/EC. However, a comprehensive set of EQO's will be required at Community and National level for all relevant dangerous substances which can occur in water. The Dutch VPR type approach compiled with use related quality objectives such as those already specified in S.I.'s 294 and 293 will provide the best basis. Whereas the production, use and disposal related issues can be controlled by addressing the entire lifecycle of and challenge the necessity for use of some of the compound in a more comprehensive and integrated fashion.

Tadg O'Flaherty,
Environmental Services,
EOLAS.

April, 1993.

21/IV/153

TABLE 1

Substances selected so far and progress made

Substance	Progress made
First series:	
1. Mercury and mercury compounds	Proposal for a Directive concerning the chloralkali electrolysis industry sent to the Council on 20 June 1979, adopted on 22 March 1982 (OJ No L 81, 27. 3. 1982) Proposal for a Directive on other industries in preparation
2. Cadmium and cadmium compounds	Proposal for a Directive sent to the Council on 17 February 1981 (OJ No C 118, 21. 5. 1981)
3. Aldrin 4. Dieldrin 5. Endrin	Proposal for a Directive sent to the Council on 16 May 1979 (OJ No C 146, 12. 6. 1979)
Second series:	
6. Chlordane 7. Heptachlor (including Heptachlorepoxide)	Communication by the Commission to the Council of 18 July 1980 (COM(80) 433 final) of which the Council took formal note on 3 December 1981
8. DDT 9. Hexachlorocyclohexane (including all of the isomers and in particular Lindane)	The studies and discussions with the national experts are now completed. Appropriate proposals in preparation
10. PCBs (including PCTs) 11. Hexachlorobenzene	Studies completed: discussions under way with the national experts
Third series:	
12. Endosulfan 13. Hexachlorobutadiene 14. Pentachlorophenol 15. Trichlorophenol	Studies completed. Discussions under way with the national experts.
Fourth series:	
16. Benzene 17. Carbon tetrachloride 18. Chloroform	Studies in progress
Carcinogens:	
19. Arsenic and mineral compounds of Arsenic 20. Benzidine 21. PAH (in particular 3,4 Benzopyrene and 3,4 Benzofluoranthene)	Studies in progress

List of substances which could belong to List I of Council Directive 76/464/EEC

*** Substances which are the subject of a proposal or a communication to the Council.
** Substances which have been or are being studied.
* Substances to be studied next.
309-00-2 CAS number (Chemical Abstract Service)

1.	***	309-00-2	Aldrin
2.		95-85-2	2-Amino-4-chlorophenol
3.		120-12-7	Anthracene
4.	**	7440-38-2	Arsenic and its mineral compounds
5.		2642-71-9	Azinphos-ethyl
6.		86-50-0	Azinphos-methyl
7.	**	71-43-2	Benzene
8.	**	92-87-5	Benzidine
9.		100-44-7	Benzyl chloride (Alpha-chlorotoluene)
10.		98-87-3	Benzylidene chloride (Alpha, alpha-dichlorotoluene)
11.		92-52-4	Biphenyl
12.	***	7440-43-9	Cadmium and its compounds
13.	**	56-23-5	Carbon tetrachloride
14.		302-17-0	Chloral hydrate
15.	***	57-74-9	Chlordane
16.		79-11-8	Chloroacetic acid
17.		95-51-2	2-Chloroaniline
18.		108-42-9	3-Chloroaniline
19.		106-47-8	4-Chloroaniline
20.	*	108-90-7	Chlorobenzene
21.		97-00-7	1-Chloro-2,4-dinitrobenzene
22.		107-07-3	2-Chloroethanol
23.	**	67-66-3	Chloroform
24.		59-50-7	4-Chloro-3-methylphenol
25.		90-13-1	1-Chloronaphthalene
26.			Chloronaphthalenes (technical mixture)
27.		89-63-4	4-Chloro-2-nitroaniline
28.		89-21-4	1-Chloro-2-nitrobenzene
29.		88-73-3	1-Chloro-3-nitrobenzene
30.		121-73-3	1-Chloro-4-nitrobenzene
31.		89-59-8	4-Chloro-2-nitrotoluene
32.			Chloronitrotoluenes (other than 4-Chloro-2-nitrotoluene)
33.		95-57-8	2-Chlorophenol
34.		108-43-0	3-Chlorophenol
35.		106-48-9	4-Chlorophenol
36.		126-99-8	Chloroprene (2-Chlorobuta-1,3-diene)
37.		107-05-1	3-Chloropropene (Allyl chloride)
38.		95-49-8	2-Chlorotoluene
39.		108-41-8	3-Chlorotoluene

40.		106-43-4	4-Chlorotoluene
41.			2-Chloro-p-toluidine
42.			Chlorotoluidines (other than 2-Chloro-p-toluidine)
43.		56-72-4	Coumaphos
44.		108-77-0	Cyanuric chloride (2,4,6-Trichloro-1,3,5-triazine)
45.		94-75-7	2,4-D (including 2,4-D-salts and 2,4-D-esters)
46.	**	50-29-3	DDT (including metabolites DDD and DDE)
47.		298-03-3	Demeton (including Demeton-o, Demeton-s, Demeton-s-methyl and Demeton-s-methyl-sulphone)
48.	*	106-93-4	1,2-Dibromethane
49.			Dibutyltin dichloride
50.			Dibutyltin oxide
51.			Dibutyltin salts (other than Dibutyltin dichloride and Dibutyltin oxide)
52.			Dichloroanilines
53.		95-50-1	1,2-Dichlorobenzene
54.		541-73-1	1,3-Dichlorobenzene
55.		106-46-7	1,4-Dichlorobenzene
56.			Dichlorobenzidines
57.		108-60-1	Dichlorodiisopropyl ether
58.	*	75-34-3	1,1-Dichloroethane
59.	*	107-06-2	1,2-Dichloroethane
60.	*	75-35-4	1,1-Dichloroethylene (Vinylidene chloride)
61.	*	540-59-0	1,2-Dichloroethylene
62.	*	75-09-2	Dichloromethane
63.			Dichloronitrobenzenes
64.		120-83-2	2,4-Dichlorophenol
65.	*	78-87-5	1,2-Dichloropropane
66.		96-23-1	1,3-Dichloropropan-2-ol
67.		542-75-6	1,3-Dichloropropene
68.		78-88-6	2,3-Dichloropropene
69.		120-36-5	Dichlorprop
70.		62-73-7	Dichlorvos
71.	***	60-57-1	Dieldrin
72.		109-89-7	Diethylamine
73.		60-51-5	Dimethoate
74.		124-40-3	Dimethylamine
75.		298-04-4	Disulfoton
76.	**	115-29-7	Endosulfan
77.	***	72-20-8	Endrin
78.		106-89-8	Epichlorohydrin
79.		100-41-4	Ethylbenzene
80.		122-14-5	Fenitrothion
81.		55-38-9	Fenthion

82.	***	76-44-8	Heptachlor (including Heptachlorepoxide)
83.	**	118-74-1	Hexachlorobenzene
84.	**	87-68-3	Hexachlorobutadiene
85.	**	608-73-1 58-89-9	Hexachlorocyclohexane (including all isomers and Lindane)
86.		67-72-1	Hexachloroethane
87.		98-83-9	Isopropylbenzene
88.		330-55-2	Linuron
89.	*	121-75-5	Malathion
90.		94-74-6	MCPA
91.		93-65-2	Mecoprop
92.	***	7439-97-6	Mercury and its compounds
93.		10265-92-6	Methamidophos
94.		7786-34-7	Mevinphos
95.		1746-81-2	Monolinuron
96.		91-20-3	Naphthalene
97.		1113-02-6	Omethoate
98.		301-12-2	Oxydemeton-methyl
99.	**		PAH (with special reference to: 3,4-Benzopyrene and 3,4-Benzofluoranthene)
100.		56-38-2 298-00-0	Parathion (including Parathion-methyl)
101.	**		PCB (including PCT)
102.	**	87-86-5	Pentachlorophenol
103.		14816-18-3	Phoxim
104.		709-98-8	Propanil
105.		1698-60-8	Pyrazon
106.		122-34-9	Simazine
107.		93-76-5	2,4,5-T (including 2,4,5-T salts and 2,4,5-T esters)
108.			Tetrabutyltin
109.		95-94-3	1,2,4,5-Tetrachlorobenzene
110.	*	79-34-5	1,1,2,2-Tetrachloroethane
111.	*	127-18-4	Tetrachloroethylene — 86/280/EEC if > 30kg/yr
112.		108-88-3	Toluene
113.		24017-47-8	Triazophos
114.		126-73-8	Tributyl phosphate
115.			Tributyltin oxide
116.		52-68-6	Trichlorfon
117.	*		Trichlorobenzene (technical mixture) — 86/280/EEC if > 30kg/yr
118.		120-82-1	1,2,4-Trichlorobenzene
119.	*	71-55-6	1,1,1-Trichloroethane
120.	*	79-00-5	1,1,2-Trichloroethane
121.	*	79-01-6	Trichloroethylene — 86/280/EEC if > 30kg/yr
122.	**	95-95-4 88-06-2	Trichlorophenols

123.	76-13-1	1,1,2-Trichlorotrifluoroethane
124.	1582-09-8	Trifluralin
125.	900-95-8	Triphenyltin acetate (Fentin acetate)
126.		Triphenyltin chloride (Fentin chloride)
127.	76-87-9	Triphenyltin hydroxide (Fentin hydroxide)
128.	75-01-4	Vinyl chloride (Chloroethylene)
129.		Xylenes (technical mixture of isomers)

Geographical Information Technology and Data Management

Putting flesh onto data

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Geographical Information Systems or GIS is a term which most of you will have heard but you may be unclear what exactly it means. This is hardly surprising as not only is GIS a new technology, but it is also one that is still developing, for although GIS has been available for a number of years it is only recently that it has started to impact on people like you, the users, and it is you the users who must dictate how it will develop in the future.

Rather than praise the wonders of GIS, in this paper I wish to give an overview of the main elements of GIS. I will concentrate on the principle elements involved in GIS as a system for environmental data management. I will outline some of the benefits of GIS especially in the fields of Hydrology and environmental monitoring and conclude with some practical steps on acquiring GIS capabilities. In summary the objective of the paper is the what, why and how of GIS.

What is a GIS

In essence a Geographical Information System is an integrated set of tools for collecting, storing, retrieving, manipulating and displaying of spatial data from the real world. How these tools are used varies greatly with the function or task that a GIS is put. In practical use GIS and its associated geographical data bases serve two distinct but related functions;

(a) As an inventory of geographical features which can be examined on the basis of their spatial or non-spatial attribute. The geographical data base maintained by Dublin Corporation of their property register is an example of an inventorial data base. This GIS allows one to identify the locations of all their property and examine the attributes of each property such as year of acquisition, condition etc.

(b) As a tool to answer questions about environmental data from diverse sources and use them to model real world situations. As such the GIS goes beyond basic storage and retrieval of geographical data and is used as an aid in decision making and policy analysis.

Components of a GIS

A GIS has four principle components - Computer hardware, Geographical data structures, the GIS software that creates and analysis those data structures, and finally a proper organisational context in which these components are used.

Computer hardware

The power house of the system is a powerful UNIX workstation or PC, either as stand alone machine or linked to other computers through a network. It should be capable of high quality graphical display and have a large internal storage memory. In recent years the dramatic reduction in the costs of computers has had the effect of making powerful computers affordable to most small and medium sized organisations. Nonetheless careful selection of computing resources is still important due to the high demands placed on computers by GIS. Input and storage devices such as Tape drives and Optical disks should be also be available to allow access and backup to the large data sets associated with geographical data such as satellite imagery, or census data. Digitisers and nowadays scanners are necessary for input of map elements. Output devices for both text and graphics are also necessary, the type and quality should reflect the particular task that the system is being put through.

Geographical data structures

The unique feature of Geographical Information Systems, as opposed to other information systems such as those used for banking, airline bookings or medical records, is the necessity to include information on objects from the real world. We need to know their position, their locational relationships to other objects around and what they actually consist of. Thus a GIS is capable of describing objects from the real world be they house sites, river networks or soil types with respect to;

(A) Their position on a known co-ordinate system,

(B) Their non-spatial attributes such as pH, vegetation type, elevation etc.

(C) Their spatial interrelation, or topological relations with each other, that is how they are linked together, or how one can travel between them.

As with conventional maps, geographical features stored on a GIS are represented by points, lines and areas e.g. wells, roads. soil associations. Data structures in GIS, however, go beyond mere representation of these map features by linking the graphical elements directly to the data they represent and attempt to represent geographical features as they are in reality. For example in the case of area features we find that many type of areas cannot be defined by discrete boundaries, but constitute a gradually changing continuum or surface. Thus in the case of elevation a GIS constructs a data structure which represents elevation as a continuously varying surface and not as a series of stepped contours. Equally for linear data such as a road or stream network we can use a GIS to characterise the elements that move through the network, assign directions and routes of flow and identify points where flow may be impeded or blocked.

Vector and Raster data structures

There are many different type of data structures in GIS, but most can be placed into one of two forms Vector based structures and Raster based structures.

Vector data structures use Cartesian co-ordinates to define geographical features, whereas raster structures record spatial data as individual cells in a grid. Both vector and raster models have their own advantages and disadvantages, therefore a fully functional GIS should be capable of utilising and cross referencing between both forms.

Vector data is commonly used to depict discrete geographical features such as sampling points, the route of a pipe or a an administrative boundary. It produces high quality cartographic output and accesses spatial and non-spatial attribute data through its topology is relatively straightforward.

The topology of a geographical data structure is used to define the relationships between the geographical features depicted in a region. In essence the topology is an attempt to define the implicit relationships we make when we look at a map. Thus when we look at a six inch map we can see the shape of a particular field, we can tell that it is bordered by a road on one side and that road leads to a certain town. Topology in a vector data set allows one to define unique points, lines and areas, to indicate the neighbours of the unique area, and to establish tracts of connectivity for line features used to define an area.

In raster structures a grid cell represents a square expanse on the ground, the area of which is defined by the resolution of the grid cell. Each cell is assigned a value which is used to identify the feature which the cell depicts. Although raster data structures can be used to depict discrete point, line and area data, it is used to best advantage where there is a gradual transition between features. One would use raster structures to model the gradual decrease in noise pollution from a motor way or a factory. Equally over an area one would use raster structures to model run-off and infiltration of rain water over different soil types and slopes.

Geo-relational data model and attribute data

Data for different types of features are usually stored as a series of layers or themes, this allows for efficient data base management, updating of features and access for analysis. This is because storing data as thematic layers simplifies the link between the graphical representation of a feature and its non-spatial attributes. Most GIS packages use a Geo-relational package to maintain this link. It is a simple concept whereby each geographical feature, whether in raster or vector structure is tagged or labelled with a unique number. Using a relational data-base this tag can be used to relate the geographical feature to tables of attribute data of the feature. For example a well site number 105, represented by a vector point and tagged as well 105, can be linked to the data concerning its depth, type and the chemical analysis of its water using that number.

GIS software

GIS software creates and stores geographical data sets and makes them available for query, analysis and presentation. The software necessary for complete GIS functionality can be broadly broken into the following sub-systems or modules;

(a) Data input and verification
(b) Data Storage and data-base management
(c) Data manipulation, query and analysis
(d) Data output and presentation

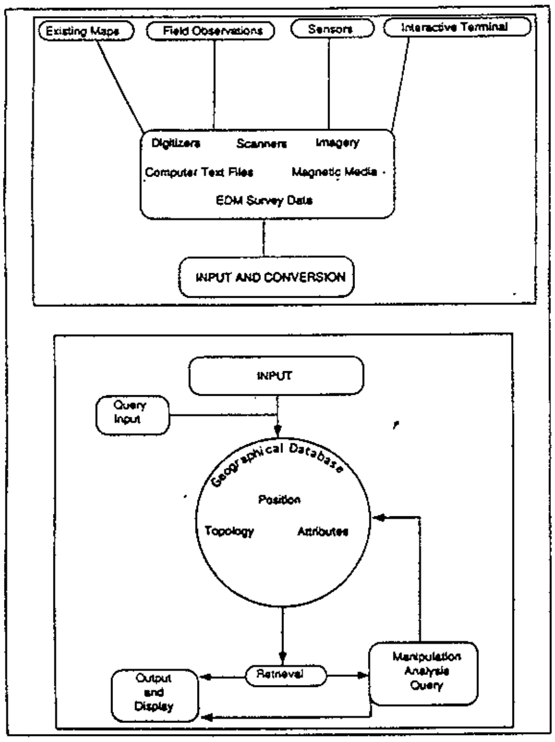

Figure 1. data input and data-base management

Data input

Data input covers aspects of converting data captured from field observations, existing maps, and sensors (e.g. Satellite imagery, data loggers, EDM survey) into a format suitable for construction of a geographic data set (see Fig 1). The data input and conversion can be one of the most costly stages of GIS operations, therefore verification of data at this point is important to ensure against errors at the data source or encoding errors of both spatial and non-spatial data.

Data storage and management

How the position, topology and attributes of geographical elements are structured and maintained in the computer memory is related to the type of data base management system used in the GIS (see Fig 1). Relational data-bases using the geo-relational model are the most common. Use of relational data-bases allows some GIS packages, such as Arc/Info to access their geographical data through other database software such as Ingress or Dbase.

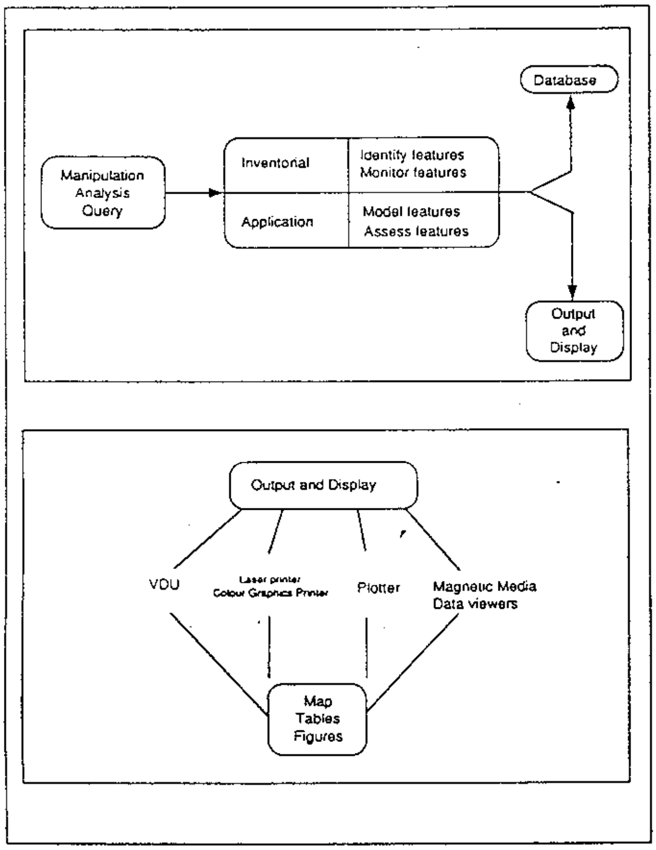

Figure 2. data manipulation and data presentation

Data Manipulation and Analysis

Data manipulation, query and analysis concerns the array of methods used to get answers to questions put to the GIS. Data is manipulated to transform it into a for suitable for comparison with other data sets, such as co-ordinate transformation of digitised data taken from maps of different projections. Manipulation may also change the format of the data structure as in the case of interpolation of point data for ground water depth to a raster model of water depth over the entire region.

The type of query and analysis carried out on a geographical data base is related to the function of the data base. For inventorial type GIS, analysis may be relatively basic and routine, one may only need to know what is the current pH levels of the surface water at a specified location or identify all sample points where the pH is above a certain level in a river quality data base for example. Also important GIS operations for such data bases will often involve efficient strategies for maintenance and upkeep of the data base.

When a GIS is used to ask more complex questions the full functionality is required. For example to identify possible locations for a land-fill site the GIS may be used initially to eliminate areas which are uneconomic or contravene statutory regulations using route way and buffer analysis in conjunction with assessment of census data. Models of soil permeability, elevation and water table depth can be constructed and overlaid with those areas which passed the first analysis. Finally sensitive environmental areas can be identified together with vulnerable environmental features in the likelihood of accidents occurring, can be overlaid and assessments made of remaining areas.

Output and presentation

Output from GIS is in the form of maps, tables, and figures. Most GIS packages allow a wide range of output formats from basic maps and graphs to very high quality cartographic copy. The type and quality of the output should reflect the task for which it is required. Output in digital form is now also possible, new products like ESRI's ArcView can address this digital output and to enable maps be shown on ordinary PC screens whilst also allowing access to the data base from which the map was based. This type of product is relatively cheap and can be used on most PC's. In the future much of the output from GIS will be in a form suitable for such products for although one cannot change the data of the output one can query the data base on both the map data and attribute data.

Organisational context

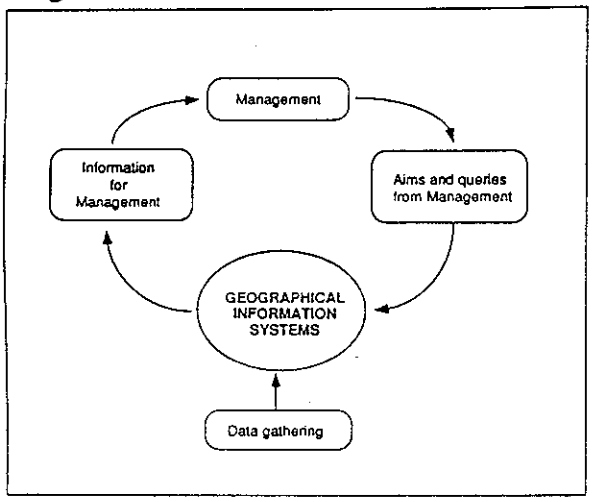

Figure 3. Information flow in the organisation.

In order for a GIS to be used effectively it needs to operate in an appropriate organisational context. The GIS should be fully integrated into the whole work practice of an organisation in order for the right type of information to be available when required by managers for decision making. It is important that the type of user and their requirements are clearly defined in relation to the expected scope of the GIS application. By user I mean not only the person operating the GIS but all those people who expect to receive information from it. Having established the required scope and demands of the GIS it is necessary to determine what channels of information together with technical and personnel resources are necessary to achieve these goals.

Why use a GIS - the benefits

The benefits of GIS technology to organisations concerned with environmental monitoring are threefold;

(a) Potential for retrieval of accurate and timely data, in its geographical context which is capable of being examined on both its geographical and attribute characteristics.

(b) Powerful analytical tools for environmental monitoring and analysis

(c) Effective presentation techniques.

The principle benefit of GIS to environmental monitoring is that it offers an integrated solution to geographical data handling and retrieval. There are increasing pressures on statutory agencies to provide accurate and timely information on all aspects of the environment. GIS as an information system aims to put in place the operational procedures necessary to ease the passage of information from the data collector to the data user. Features such as the ArcView data viewer allows cost effective distribution of geographical information stored on the main GIS installation and retrieved from it.

For analytical work the powerful array of geo-modelling tools in a GIS can provide novel solutions to hydrological problems. Thus for example modelling infiltration and flow rates in a basin, construction of surfaces depicting ground water depth in meters above sea level or analysis of the impacts of land-use change and agricultural inputs on ground water quality can all be addressed in the GIS.

The display functions of GIS enable effective presentation of information in a form which is more comprehensible to decision makers and members of the public. In the areas of water and waste management this has obvious benefits as these areas arose great public interest. Presentation of data in a digestible form will aid in allaying the general public.

How to acquire GIS capabilities

When an organisation has established the scope of its GIS requirement there are a number of strategies open in order to satisfy that requirement. These strategies can be either;

(a) Full commitment to GIS involving purchase of equipment and software, hiring or re-training staff, generation of data-bases internally and analysis of organisational procedures with possible changes of these procedures.

(b) Partial commitment involving hiring of outside agencies to carry out some or all of the GIS functions required.

Full commitment to GIS requires high financial outlay and a strong commitment from both staff and management. This may not be the most appropriate route for some organisations and taking advantage of an established GIS service may prove a more cost effective method of using GIS technology. Equally the GIS requirements of an organisation could be satisfied using products such as ArcView with the GIS agency establishing, and maintaining the data-base on a full GIS and distributing the data for ArcView as appropriate. This can be a very cost effective method of having some GIS capability without the type of outlay required to establish a GIS internally.

The use of outside agencies can ensure that the geographical data-bases required are actually operational before full commitment to a GIS. Furthermore the initial input of data of a geographical data-base may be better handled by outside agencies as often the type of effort necessary to set up the data base will not be needed to maintain and update it.

Conclusion

Geographical Information Systems are increasingly been seen as an invaluable tool for environmental data management. They provide an integrated approach to handling and analysing data about the environment. As information systems they will possibly have a similar impact on the 'Environmental Business' as the introduction of information technology has on other businesses. Therefore their introduction to an organisation needs to be carefully thought out and planned, in order to achieve maximum return. However taking advantage of outside agencies for some or all of an organisations GIS requirements can ease the process.
