INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH GROUP)
10th Annual Seminar

CLIMATIC EXTREMES AND THEIR EFFECT ON WATER RESOURCES

PROGRAMME

TUESDAY 1st MAY		SPEAKER AND ORGANISATION
10.15	Registration and Tea/Coffee	
10.45	Welcome and Introduction	Bob Aldwell (President, Irish Group IAH)
11.00	'Short term prospects for global climate and their implications for Irish regional precipitation yields'.	Dr. John Sweeney, Dept. of Geog., St. Patrick's College, Maynooth.
11.45	'Climatic extremes and the Irish Climate'.	The Meteorological Service.
12.15	'River flows'.	John Martin, OPW.
12.45	Discussion	
13.00	**Lunch**	
14.00	'River water quality'.	Martin McGarrigle, ERU.
14.30	'The likely effects of significant climatic changes on the flow regime in the principal Irish aquifers'.	Eugene Daly, GSI.
15.00	'Floods, drought and groundwater quality'.	Dr. Richard Thorn, Sligo RTC.
15.30	**Tea/Coffee**	
16.00	'Flood warning and prevention in Co. Kilkenny'.	OPW.
16.15	'Drought and water resources - the sub-Saharan experience'.	David Ball, ERA/Maptech.
16.45	Discussion.	

WEDNESDAY 2nd MAY

9.45	'Climatic extremes and agriculture'.	Tom Keane, The Meteorological Service.
10.00	'The Local Authority experience'.	Wexford Co. Co. Tom Fitzpatrick, Westmeath Co. Co.
10.30	'Climatic extremes and the ESB'.	Electricity Supply Board.
10.45	**Tea/Coffee**	
11.00	'Floods and low flows - the U.K. experience'.	Rick Brassington, National Rivers Authority, NW Region.
12.00	Discussion	
13.00	**Lunch**	

This programme is provisional and may be subject to alteration

Groundwater Report - Summary Sheet

Report Number: GW 90/? Author(s): R.THORN (ed.)

Report Title: Climatic Extremes and their Effect on Water Resources.

Date Completed: May 1990

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

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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: Climatic Extremes, Water Resources, Floods, Lowflows and Droughts.

Geological Succession Covered: The Principal Aquifers in Ireland

Objectives in Writing Report: ______

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

PARTICIPANTS IN 10th ANNUAL IAH SEMINAR PORTLAOISE MAY 1990

Aldwell, Bob	Geological Survey, Dublin
Ball, David	ERA/Maptech, Dublin
Bennett, Peter	Hydrogeological Services Belfast
Bourke, Mary	Geog.Dept.UCD
Brassington, Rick	Nat Rivers Auth NW Region UK
Byrne, Shem	Wexford County Council
Callery, Phillip	Wexford County Council
Cawley, Tony	Eng. Hydrology UCG
Clarke,Brendan	Offaly County Council
Condon,James	Limerick County Council
Coxon, Catherine	K T Cullen Dublin
Coyle , Fergus	Monaghan County Council
Creaner, Sandra	Geog.Dept UCC
Crowe, Patrick	Tipperary(NR) County Council
Cullen, Kevin	Consultant Dublin
Daly, Donal	Geological Survey, Dublin
Daly, Eugene	Geological Survey, Dublin
Daultrey, Stuart	Geog.Dept.UCD
Dowley, Aodh	Civil Engineering UCD
Drew, David	Geog. Dept. TCD
Duane, Gerard	Meath County Council
Dunne, Paddy	Drumiskin, Dundalk
Dunne, Ronnie	Department of Environment
Dunne, John	Dunnes Well Drilling Mallow
Fitzgerald, Denis	Meteorological Service Dublin
Fitzpatrick, Tom	Westmeath County Council
Flynn, Ronan	Central Fisheries Board Dublin
Forde, Gerard	Wexford, County Council
Galvin, Gerry	N ODwyer Consultant Dublin
Hayes, Dermot	State Laboratory
Henderson, Richard	Sligo RTC
Higginson, John	Carlow County Council
Keane, Tom	Meteorological Service
Lynch, James	Meath County Council
Maguire, Tony	Waterworks Dept. Dublin Corp.
Mannion, Oliver	Kilkenny County Council
Markey, Eamonn	Department of Environment
Martin, John	Office of Public Works Dublin
Mc Evoy, Harry	GSI, Dublin
Mc Garrigle, Martin	Department of Environment
Mulholland, John	Kilkenny County Council
Murphy, Arthur	Consultant, Wexford
O Donoghue, Denis	Hollyfort, Gorey
O Gorman, John	Roscommon County Council
O Leary, Denis	Department of Environment
Other, An	Laois County Council
Other, An	Laois County Council

Other, An	Tipperary(NR) County Council
Other, An	Eng. Hydrology UCG
Other, An	Eng. Hydrology UCG
Other, An	ESB
Other, An	Eng.Hydrology UCG
Peel, Stephen	Minerex Ltd. Dublin
Power, Jackie	Wexford County Council
Regan, Sean	Eng. Hydrology UCG
Richard Henderson	Student Sligo RTC
Shine, Harry	Office of Public Works
Sweeney, John	Geog. Dept. Maynooth Univ.
Thorn, Richard	Sligo RTC
Tweeney, Charles	Laois County Council
Walsh, Joe	J K Walsh Scientific Dublin

DAVID BURDON COMMEMORATION LECTURES

In memory of our late President Dr. David J. Burdon, the Irish Group of IAH are organising a series of lectures to be known as the "David Burdon Commemoration Lectures".

The general theme will be "TRENDS IN HYDROGEOLOGY".

Leading international hydrogeologists will be invited to Ireland to give the lectures, which will be delivered at different venues throughout the country.

So far, preliminary approaches have been made to speakers from Czechoslovakia, Denmark, Spain and the USA.

The first speaker is to be Dr. Philip LaMoreaux from the USA. Phil LaMoreaux is a highly experienced hydrogeologist having worked in both the public and private sectors in the USA and has extensive work experience in many parts of the world. He is a former World President of IAH and currently Chairman of the IAH Commission on Hazardous Wastes.

He plans to be in Ireland from May 6th to May 12th 1990 and is scheduled to give the following lectures.

1. <u>Legal and hydrogeological aspects of hazardous waste disposal in the USA.</u>
   Venue: Geological Survey of Ireland, (Beside Labour Court), Beggars Bush, Haddington Road, Dublin 4. <u>May 7th at 6.15pm.</u>
   Contact person: Bob Aldwell, Geological Survey of Ireland.

2. <u>Hydrogeological and geotechnical aspects of hazardous waste disposal sites.</u>
   Venue: University College, Cork. <u>May 9th at 8 p.m.</u>
   Contact person: David Orr, Dept. of Civil Engineering, U.C.C.

3. <u>Problem of hazardous waste disposal in limestone regions.</u>
   Venue: Sligo RTC. <u>May 10th at 8 p.m.</u>
   Contact person: Richard Thorn, Sligo RTC.

SHORT TERM PROSPECTS FOR GLOBAL CLIMATE AND THEIR IMPLICATIONS FOR IRISH REGIONAL PRECIPITATION YIELDS

John C. Sweeney,
Department of Geography, St. Patrick's College, Maynooth

INTRODUCTION

In common with most of society, hydrogeomorphologists have, in the past, implicitly worked on the basis that climate is a fixed, stable commodity which can be characterised by aggregates and averages derived from a long period of observations. Conventionally, a 30 year period has been used to establish the so-called climatic 'norms' of a location and to derive the means, extremes and frequencies of the weather elements which give a place its unique climatic fingerprint. Thus, climatologists could supply hydrogeomorphologists, for example, with information on the likely return period of rainfall events or on precipitation/evaporation relationships, considerations important in the management of surface and groundwater resources. It is now clear that such baselines cannot be extended into the past, or more seriously, into the future, with any degree of certainty. That climate changes on all scales is now an accepted fact, and that global climate may change more radically over the next few decades than over the last few millennia is increasingly likely.

GREENHOUSE GASES: TRENDS AND PROSPECTS

The principal absorbers of infra red radiation in the atmosphere are clouds, water vapour, carbon dioxide and ozone. In addition to these, Methane, Nitrous oxide, and Chlorofluorocarbons also absorb terrestrial outgoing radiation very effectively. Analysis of air bubbles embedded in cores taken from ice sheets indicate that some of these gases have increased their concentrations substantially since pre industrial times, and their now enhanced radiative properties pose an increasing threat to global climate.

Carbon Dioxide: Concentrations of CO_2 in the mid 18th Century were about 280 ppm. By 1988 they had risen to 351 ppm (Warrick and Farmer, 1990). and are currently increasing by about 1.5 ppm per annum, principally due to annual anthropogenic emissions of 5.6 billion tonnes of equivalent carbon from fossil fuel combustion. A further 1.5 billion tonnes comes from the deforestation of tropical rainforest. About half of these emissions are removed by natural mechanisms, the remainder adding to the atmospheric pool of greenhouse gases.

Historically, growth rates of 4.5% in emissions are apparent, though since the oil price increases of the 1970s rates of growth of about half this value have been the norm. Oil and coal are approximately equal contributors. The developed industrial economies account for about 85% of emissions at present, though emission growth rates of 5% in the developing world imply that much of the increase in future years will come from these areas. Indeed the coupling of energy consumption and economic development which has been a feature of the industrialisation process ensures that restriction of CO_2 emissions will be a particularly intractable problem in Third World countries and render the likelihood of a doubling of pre industrial levels sometime in the period 2020-2050.

Methane: Methane concentrations have already doubled from their pre industrial level of 0.8ppm and now stand in excess of 1.7 ppm. In addition to being related to energy consumption, Methane is also an emission related to agricultural expansion, most notably paddy rice production and livestock rearing. Its prospects for control are thus even more difficult to envisage as global population and thus food demand increase.

Nitrous Oxide: A much slower rate of growth for this gas is apparent, with concentrations today only about 10% above pre industrial levels. Agriculture and energy use are again the main anthropogenic sources, particularly the increasing use of artificial fertilsers.

Chlorofluorocarbons: Most widely known for their destructive effects on stratospheric ozone, CFCs are also very powerful greenhouse gases. Radiatively they are (on a molecule for molecule basis) 10,000 times more effective as absorbers of terrestrial radiation than CO_2 though their concentrations are presently miniscule by comparison. During the past decade they have, however, increased their concentration by over 5% per annum and in the absence of control would have become highly significant accelerators of greenhouse warming, second only in importance to CO_2 within the next forty years. The Montreal Protocol for their control, if applied rigidly, buys the earth about eight years in the warming process (Wigley, 1988). Undoubtedly, these are the easiest greenhouse gases to control, requiring little in the way of fundamental lifestyle changes for the developed world, though it remains to be seen how effectively their control can be achieved in rapidly developing economies in the Third World.

Computing the radiative effect of these and other minor greenhouse gases (such as tropospheric ozone) is fairly straightforward and suggests their combined present temperature impact is about half that of CO_2 alone. In most models, therefore, their effect is incorporated in terms of an equivalent amount of CO_2.

MODELLING OF THE GREENHOUSE EFFECT

Today's most powerful computers are about 1,000 times as fast as their predecessors of the early 1970s, enabling the incorporation of more information into numerical models and also permitting increasing resolution in their treatment of climate. Seasonal and regional details are just beginning to emerge as possibilities, as is the question of the variability characteristics of future climate.

The range of performance of climatic models has also narrowed substantially. Fairly good agreement with observational data is apparent for pressure simulations, particularly for low latitudes. Polewards of 60° a considerable problem still exists due to the as yet unsolved difficulties of the ice-albedo feedback effect mentioned below. In contrast, with precipitation, the greatest uncertainties lie at low latitudes, where large discrepancies with observed data are still common. In this case the other major problem of the incorporation of cloud into the models is the cause.

Despite these generally encouraging results there is as yet no model which has been able to incorporate all of the physical processes deemed important influences on past or future climatic modes. Most disappointingly of all, regional scale predictions are not as yet possible since the grid mesh used for the computer runs are typically 8-10° or about four times the area of Ireland. Extreme caution regarding regional scenarios of climate change is therefore essential at this stage. In particular, two complex feedback mechanisms constitute the major obstacles to progress in all areas.

Feedback Mechanisms: The present global albedo is 0.30, meaning that 30% of incoming short wave radiation is reflected straight back to space. The albedo determines how much solar energy is left to warm up the atmosphere. A strong determinant of the albedo is the area of snow and ice (a surface with an albedo in the range 0.7-0.9) exists. Warming is likely to melt substantial amounts of high latitude ice, darken the surface and thus accentuate the warming trend - a positive feedback effect.

Water vapour effects are more problematical, however. since water vapour is the most effective greenhouse gas of all. Warming is likely to enhance evaporation and cloud formation. More clouds should mean more trapping of terrestrial heat - again a positive feedback effect. However, more cloud cover should also increase the albedo and reduce warming of the lower troposphere - a negative feedback effect. Current models have not fully resolved which effect is dominant.

Thermal Inertia of the Oceans: Linking the ocean system to the atmospheric system has proven extremely difficult. The ocean is an essential element in the understanding of greenhouse warming since it acts both to remove carbon dioxide from the atmosphere and to absorb and redistribute heat throughout its great volume. The upper three metres of the ocean store as much heat as the entire atmosphere. Response times for the ocean system are however much longer than the atmosphere and coupling the two systems has been difficult. In one case an oceanic model was run for the equivalent of 4,200 years and then coupled to an atmospheric circulation model run for the equivalent of 4 years. Most general circulation models still greatly simplify the ocean and do not allow for circulation changes in the ocean feeding into the climatic model.

GENERAL CIRCULATION MODEL - RESULTS

Considerable uncertainty exists regarding future global energy consumption. Projected carbon emissions correspondingly range widely. Best estimates suggest a doubling of pre industrial concentrations in about 40 years from now, and most models use this as the reference point for their output. Results of the most recent major modelling exercises are in broad agreement on a number of fronts.

Firstly, global mean temperature will increase by 3°C +or- 1.5°C. compared with the beginning of the present century (Dickinson, 1986). Because of the ice-albedo feedback effect this warming will be greatest at high latitudes and more pronounced in winter. This is largely a consequence of the ice-albedo feedback effect referred to above and also implies that high latitude precipitation should increase. For the year 2030 the best estimates suggest a global warming of 1-2°C compared with present values. A rise of 2°C, in addition to being extremely rapid (a poleward shift of isotherms by 50-75 km/decade), would mean the earth would be warmer than at any time since the peak of the last interglacial, 120,000 years ago. Rises of 5°C and above, projected for later in the century, would take global climate back to temperature regimes not experienced since the Oligocene/Miocene epochs of the Tertiary Period, 38-15M years B.P.

Secondly, almost irrespective of which energy scenario is chosen, global warming of 0.5°C is apparent within the next 15 years and this is equivalent to a departure of 3 standard deviations from the climatology of the 1950s. For such a level to be attained and maintained would be considered definite proof of a greenhouse signal, and this is confidently expected to be detected during the 1990s (Hansen *et al*, 1988).

Thirdly, since warmer air can hold more water vapour, the intensity of the global hydrological cycle is likely to increase. It is reasonable to suggest that globally, an increase in precipitation is likely. This has been estimated at between 3 - 11% (Manabe and Stouffer, 1980; Rind and Lebedeff, 1984). This is strongly suggested as being most marked in the high latitudes. Increases elsewhere may not be sufficient to compensate for increased evaporation. Though precipitation changes are likely to be the key climatic change associated with greenhouse warming, it is much more problematical to anticipate than temperature.

Fourthly, though there is often a less clear signal in the model outputs, some broad regional implications may be inferred from the reduction in the equator-pole thermal gradient. These include less reliable rainfall in sub Saharan Africa, a drying out of soil moisture in continental interiors such as North America and a more reliable monsoon over most of south Asia.

Changes in Global Sea Level: Various studies (Gornitz and Lebedeff, 1987; Barnett,1983;1984) suggest that a sea level rise of 10-15cms has occurred in the past 100 years, at least some of which may be attributable to the global warming of 0.5°C which has occurred over the period (Wigley and Raper, 1987). Thermal expansion constitutes the most likely cause of greenhouse led rises in sea level over the next century, with a best estimate in the range 8.4-10.0 cms. To this must be added a slightly smaller amount which will occur due to melting of small terrestrial ice masses. Antarctica is likely to accumulate ice and contribute to a lowering of sea level in the immediate future. Alarmist statements about the potential melting of the West Antarctic Ice Sheet are almost certainly misplaced and recent estimates by Budd et al (1987) suggest that even a one metre rise due to melting of this grounded ice sheet would take up to 500 years to occur.

Nevertheless, even a small rise in sea level constitutes a major hazard in delta areas such as the Nile and in Bangladesh. Very low lying coral islands are also most susceptible. The Maldive Islands for example have 120,000 inhabitants, all living 2-3 metres above present sea level.

Rising sea level also impinges on river flow regimes and sedimentation rates, tending to increase deposition in the lower courses. This would also of course increase flood hazard. Salinisation of coastal areas is another problem with the intrusion of saline water into coastal aquifers leading to contamination of domestic water sources in some instances.

THE IRISH CLIMATIC RESPONSE TO GREENHOUSE WARMING

Climatic modellers are keen to stress that regional climatic forecasts based on general circulation models are not yet possible to make with any degree of confidence. Such are the uncertainties involved that only tentative suggestions are as yet feasible for areas such as Western Europe. For Ireland, a comparison of four gcms suggests a mean annual temperature increase in the range 3.0-5.5°C for a doubled CO_2 climate run. Seasonally, a rather larger increase is expected in winter than summer.When these gross generalisations are more closely examined, however, even less confidence can be placed in them, given what is already known about the way Irish climate responds to its principal controls.

The Importance of the Upper Westerlies: The upper westerly circulation dominates Irish climatology, providing advection of heat from ocean to land, the conditions conducive to depression formation and passage, and the driving force for the North

Atlantic Drift. The upper westerlies are driven by the Equator-Pole temperature gradient, being stronger when the temperature difference is large (such as in winter) and *vice versa*. Global warming, expected to be greatest at the higher latitudes, will diminish this gradient and thus diminish the intensity of the upper westerlies. Indeed this process may be considered to be already underway with the number of days of true westerly weather over Ireland having approximately halved over the past 50 years. Diminished westerlies would however be expected to be associated with increased circulations from other directions, most probably from continental sources. In winter, even in a warmed climate, this would bring colder air masses to Ireland more frequently than at present. Blocking could become more common and winters and springs in Ireland might not be expected to become significantly warmer than at present. Such a surprising scenario for past warmer times in Europe was suggested from an examination of past warm analogues by Palutikof et al (1984) and demonstrated the danger of simplistic interpretation of global climate models. Irish summers may be expected to be substantially warmer with increased blocking frequencies.

The critical importance of deciding how the westerlies will behave is especially significant for precipitation. The geography of Irish precipitation receipt is an expression of the shelter or otherwise provided by relief obstacles to the westerly circulations. With circulations other than westerly, the distinctive west-east contrast in receipt diminishes. Regional rainshadow areas are clearly apparent in the lowlands along the Foyle, east of the Sperrins and along the east and south coasts. The most conspicuous anomaly lies in County Limerick, the only area where the 1,000mm isohyet reaches the west coast. Protected by the relief obstacles of the Cork-Kerry mountains to the south, and the mountains of Connemara and the Burren to the north, this is an area open to the receipt of rainfall only with true westerly trajectories. In terms of sensitivity to a greenhouse led reduction in westerly circulations this is the area where the first rainfall effects will be seen, perhaps in terms of an increasing proportion of winter rainfall coming on fewer days of westerly circulation. The following tentative scenario for hydrological impacts may be suggested for Irish climate for a doubled CO_2 scenario:

(i) Warmer and slightly wetter summers with increased variability in rainfall receipt. Summer temperatures at least 3°C warmer than at present are likely to be the norm by mid century. An increasing tendency for soil moisture deficits will exist in all summers, and longer spells of drought during the early summer months will be more common.

(ii) Winter temperatures may not be significantly different from the present. Springs may be slightly cooler if anything. Winter rainfall will however be probably slightly reduced in total and certainly less raindays can be expected, particularly in western parts.

(iii) The geographical contrast between western and eastern Ireland will diminish noticeably in magnitude as more cyclonic and other circulations replace a declining westerly circulation. Precipitation receipts from disturbances carried in the westerly circulation will however be higher than at present due to their enhanced water vapour carrying capacity. This means a possibly increased flood risk from winter depressions.

(iv) Increased variability will characterise Irish precipitation. The existing concepts of return period for rainfall amounts and intensities, and river flow regimes, will thus require revision and it may be dangerous to plan long life civil engineering structures on the basis of the 1951-80 or even 1961-90 climatic averages. This is because even small changes in mean climatic characteristics manifest themsleves in larger changes in extremes. This can occur even without changes in the standard deviation i.e. even if aspects of climate do ***not*** become increasingly variable, the incidence of some extremes may increase substantially. Wigley (1989) estimated that a climatic event which initially has a 1-in-a-100 chance of occurrence in a given year will, with a change in the mean of one standard deviation, have a new probability of occurrence of 1-in-10 i.e. a tenfold increase. Thus, if rainfall were to increase by even a modest amount the hydrological impact might be considerable.

Finally, the scenario for greenhouse warming depends on the melting of considerable sea ice in the higher latitudes. Until this occurs the Equator-Pole temperature difference may actually be increased, with the planetary circulation having to move greater amounts of heat polewards in the short term. It is thus possible that in the short term, say 10-30 years, more vigorous storm activity may be a feature of the North Atlantic and North Pacific, and enhanced hurricane development in the tropical oceans a counterpart to this. Thus while a greenhouse warmed world may be more benign to Ireland than almost any other mid latitude location, it may be preceded by major changes in strom frequency and intensity, a phenomenon with considerable hydrological implications.

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DENIS FITZGERALD
Meteorological Office, Glasnevin, Dublin

What is the CLIMATE ?

If nobody asks me, I know !

If asked and I want to explain it, I don't know

After this Confession may I hope for your absolution - as to the offence to St. Augustine, perhaps in time he will forgive this gross plagiarism.

Climatology is about the collection of information on the state and behaviour of the atmosphere (Jagannathan,1967)

Would now add some such phrase as 'and all its exchanges and interactions with the earth's surface'

Key Elements:

- Temperature
- Pressure
- Wind
- Moisture Content
- Precipitation
- Sunshine
- Cloud
- Solar Radiation
- Evaporation
- Radiation Balances
- Chemical Exchanges

Definition of Climate .... Hann (1903)

Sum of meteorological phenomena which characterise the average condition of the atmosphere at any one place on the earth's surface

Emphasis on AVERAGE CONDITIONS or NORMALS

Doctrine ....Climate is essentially constant over periods that are long compared with the human lifespan

In modern practice a normal is a 30-year average

Normal has unfortunate connotations :

- common
- frequent
- an expected state

Modern View of what constitutes climate :

Recognises the importance of long term averages(in such as comparison studies) but regards them as only one of a battery of Descriptive Statistics

Emphasis on VARIABILITY, FREQUENCY of OCCURRENCE, EXTREMES and PERSISTENCE of states of interest

Risk assessment of great importance

Exploratory Data Analysis

1. Quality Control
2. Graphical and Tabular Displays
3. Statistical Tests
4. Descriptive Statistics

Hope from steps 1 to 4 to get some indicators of structure or pattern

In many cases get what you want from 2 and 4

In some cases use the indications gleaned from the data to proceed to INFERENTIAL STATISTICAL ANALYSIS or STOCHASTIC MODELLING

Propose to use the rainfall climate to illustrate the methods of exploratory data analysis and to make some points which apply no matter what climate element we discuss. These amount to asking oneself beforehand what the purpose of the enquiry is, i.e. to posing questions of the following kind:

(1) What is the time-scale(s) of interest.... annual,monthly,daily or hourly ?.

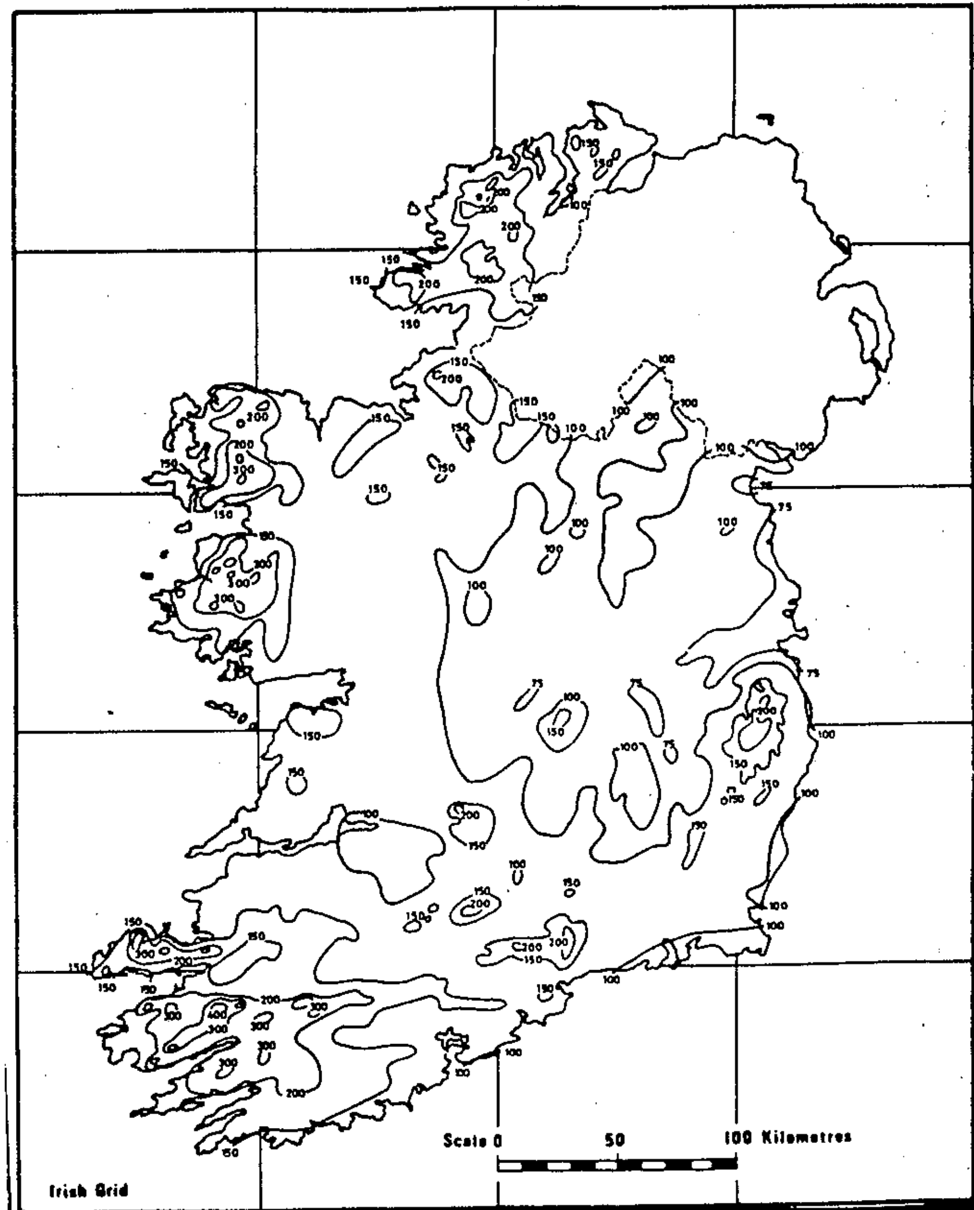
(2) Is the magnitude of the event of prime interest and are central values of more importance than extremes?.

(3) Is the duration of certain conditions of interest or are interoccurrence times of more concern?

(4) Does the data available contain the information I want?. If so,what are the best techniques for extracting it?. If not.......!!

MEAN MONTHLY RAINFALL (mm)
1951 - 1980

JANUARY



CLONAKILTY

JANUARY RAINFALL CLIMATE

1951-80

3	62
4	1
5	
6	
7	2
8	
9	31
10	46
11	225
12	1
13	8098
14	993
15	250
16	51
17	
18	080
19	
20	
21	
22	
23	
24	1
25	
26	7
27	6

	mm
Mean	138
Median	138-139
Highest	276
Lowest	32

10% > 240	20% > 179
10% < 42	20% < 92

On Average

Wettest month is January
Driest month is June
(Average 61mm)

Highest Monthly Total
276mm Jan 1974

Lowest Monthly Total
3mm Aug 1976

1951-80 Annual Average
1202mm

Range 860 - 1627mm
(1952) (1960)

For monthly totals the map summarises a lot of information and makes COMPARISONS easy.

The more particular data presented for Clonakilty gives a very different indication of the distribution of the monthlly totals at one site.

What of the daily falls that make up the monthly totals?.

We would guess that most of the daily falls are low-intensity events.

The following facts substantiate this claim:

(1) average monthly totals divided the average monthly duration is between 1 and 2 mm per hour.

(2)number of days with 5mm or more is roughly half the figure for days with 1mm or more. The number with 10mm or more is again about half that for a 5mm threshold.

EXTREME 1-DAY FALLS

In Ireland the record is 206.5 mm (+6.7) in the Caragh River area of Kerry on 5/6 August 1986.
For comparison the falls in lowland areas of Dublin during 'Hurricane Charley' were about 80mm, with about 180mm in the mountains.
We estimate that these 1-day falls have a return period of more than 100 years - probably about 150 to 200 years.

The next transparency shows falls of from 1 day to a calendar month for the period 1960-1984 at widely differing locations.
We see that nowhere is the 8-day fall more than 3 times the 1day and is mostly about twice the 1day. In general high falls,as well as being infrequent,are usually followed by much lighter falls.
This generality is valid but in meteorology it is a good policy to pay a lot of attention extremes and exceptions.

Table 17

MAXIMUM AMOUNTS OF RAINFALL IN STATED PERIODS OVER THE 25-YEAR PERIOD 1960-1984

Station	Height Above M.S.L.	Annual Average Amount 1951 - 80	Maximum amounts recorded in:				
			1 day	2 days	4 days	8 days	Calendar Month
	m.	mm.	mm.	mm.	mm.	mm.	mm.
Athlone O.P.W.	34	901	65.0	67.1	70.9	109.1	166.6
Ballinacurra	5	1004	75.2	93.7	101.4	136.8	255.1
Ballyshannon (Cathleen's Fall)	36	1061	62.2	66.3	83.2	112.0	202.4
Belmullet	9	1101	58.2	74.6	93.6	117.1	236.8
Birr	70	816	53.6	62.3	76.0	90.5	151.7
Carndonagh (Rocksmount)	27	1148	43.1	62.5	85.8	118.3	230.1
Casement Aerodrome	91	728	53.5	74.1	93.3	109.6	171.2
Claremorris	69	1113	82.9	94.4	115.2	128.2	224.0
Clones	87	917	64.3	69.8	87.2	116.8	166.6
Cork Airport	151	1229	79.9	123.3	129.3	165.4	342.7
Cuilcagh Mountains	308	1845	91.0	105.1	132.6	188.3	349.3
Delphi Lodge	30	2542	123.0	183.0	223.8	319.7	495.1
Dublin Airport	68	750	51.0	71.9	97.6	110.3	217.0
Dundalk (Annaskeagh W.W.)	58	967	65.8	114.6	124.5	155.5	285.1
Kilkenny	63	826	66.4	66.4	72.2	104.0	200.0
Malin Head	20	1041	57.7	71.7	89.3	108.2	223.6
Mallow (Hazelwood)	91	970	46.5	68.8	77.4	132.2	238.0
Markree Castle	37	1139	58.4	86.4	106.7	115.8	234.7
Mullingar	101	922	75.9	97.3	120.9	130.4	203.3
Portumna O.P.W.	33	839	57.4	63.2	102.6	109.8	181.9
Roches Point	40	934	78.8	94.4	95.2	116.2	220.5
Rosslare	23	887	81.5	88.0	120.2	142.3	210.2
Roundwood (Filter Beds)	192	1204	71.3	112.2	145.5	186.4	405.2
Shannon Airport	3	919	48.7	60.0	81.0	99.6	190.1
Silvermines Mtns. (Curreeny)	309	1603	73.9	88.5	112.7	157.1	325.0
Valentia Observatory	9	1400	115.7	155.5	157.3	178.9	319.7

* Readings taken at 0900 GMT

10.

Hourly Falls

At Kilkenny over a 20-year period there were only 2 hours with >20mm
12 hours with >10mm
91 hours with > 6mm (heavy rain)
out of a total of 23,228 hours with rain.

This supports the general contention of a rainfall climate preponderantly of low-intensity events.

However at Orra Beg, Co. Antrim there was a fall of 97 mm in 45 minutes in August 1980.

In June 1963 we had 83 mm in 65 minutes at Mount Merrion, Dublin.

Even at Kilkenny itself were we content merely to observe the very low frequency of >20mm in an hour we should miss some very important and interesting data by not pressing on to shorter period falls.

KILKENNY LAT. 52 40N LONG. 07 16W ELEVATION 63M ABOVE MSL

NUMBER OF OCCURRENCES OF SPECIFIED RANGES OF RR AMTS BETWEEN EXACT HRS GMT

ALL HOURS

IN MM	JAN	FEB	MAR	APL	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0.1	661	472	536	447	536	323	373	365	430	495	564	675	5877
0.2	375	260	252	265	250	202	208	198	249	244	277	333	3113
0.3	291	192	217	175	227	134	129	131	174	159	181	246	2256 — 50%
0.4	174	160	155	123	154	101	97	104	136	134	141	178	1657
	164	108	111	104	100	89	95	92	92	126	136	134	1351
0.6	127	98	100	75	104	78	63	67	78	106	98	111	1105
0.7	117	67	87	85	87	51	62	61	80	69	66	93	925
0.8	83	55	68	62	71	43	49	41	56	65	84	86	763 — 75%
0.9	86	61	33	54	58	33	40	40	48	58	58	56	625
1.0	77	48	54	41	46	45	39	25	52	45	61	60	593
.1-1.2	116	97	60	71	73	47	72	63	81	80	85	107	952
.3-1.4	97	64	49	60	53	48	60	39	55	58	76	71	730
.5-1.6	83	47	52	52	45	32	45	36	54	46	76	85	653
7-1.8	54	35	36	40	36	20	33	30	40	45	41	60	470
9-2.0	37	24	26	23	37	20	23	25	42	36	46	61	400
.1-2.5	78	47	41	51	47	45	41	45	64	80	78	69	686
.6-3.0	50	24	19	13	34	19	18	30	40	36	36	45	364
1-3.5	23	15	12	17	11	8	25	25	35	25	21	12	229
6-4.0	18	7	5	3	10	12	19	12	15	21	13	15	150
1-4.5	6	7	3	4	11	4	10	7	14	15	12	19	112
.6-5.0	7	3		1	3	3	5	6	11	9	11	2	61
.1-6.0	1	6		2	4	3	8	10	16	4	5	6	65
1-7.0	2		1	1	2	1	4	4	7	10	2	2	36
1-8.0	2	1	1		1	1	2	5	2	4	1		20
1-9.0	2	1			1	2	2		3				11
1-10.0					1		4		2	2	1		10
1-11.0							1	1			2		4
1-12.0									1				1
1-13.0				1				1		2			4
1-14.0													
1-15.0							1	1					2
1-16.0													
1-17.0						1							1
1-18.0													
1-19.0													
1-20.0													
20.0				1				1					2
TAL	2731	1899	1918	1771	2002	1365	1528	1465	1877	1974	2172	2526	23228

Table 18

HIGHEST RAINFALL AMOUNTS (mm) RECORDED AT SPECIFIC STATIONS WITH RECORDS AVAILABLE UP TO AND INCLUDING DECEMBER 1984

Station	Amount Recorded in									Records from
	15 mins	30 mins	1 hr	2 hrs	3 hrs	4 hrs	6 hrs	12 hrs	24 hrs	
	mm	mm	mm	mm	mm	mm	mm	mm	mm	
Belmullet	15.4	21.9	26.9	29.2	34.8	36.1	40.3	43.5	60.0	1957
Birr	17.4	25.8	30.2	38.7	39.4	39.5	39.5	52.7	61.0	1955
Casement Aerodrome	14.6	19.9	22.8	26.4	27.3	29.5	33.7	52.5	56.8	1959
Claremorris	13.6	23.0	34.6	43.1	55.3	62.2	72.6	87.5	90.3	1944
Clones	15.8	20.7	28.8	42.1	51.2	58.2	61.8	62.0	64.3	1950
Cork Airport	13.6	15.8	22.7	41.2	52.5	58.2	66.4	75.5	93.3	1963
Dublin Airport	20.5	23.4	27.0	41.0	42.9	45.6	50.3	53.2	57.6	1940
Galway	9.4	16.3	17.3	22.4	22.4	23.8	30.6	41.3	56.4	1979
Kilkenny	23.5	31.6	37.9	56.7	62.5	64.7	65.7	66.4	66.4	1958
Malin Head	9.9	14.7	17.7	21.0	23.4	26.6	36.5	55.7	67.4	1957
Mullingar	20.9	26.6	34.5	37.4	48.5	52.8	62.5	69.8	80.0	1944
Roche's Point	13.8	17.2	23.7	28.5	34.6	40.6	52.9	73.1	85.0	1956
Rosslare	15.0	20.8	33.0	49.5	53.2	57.2	60.8	79.9	81.5	1957
Shannon Airport	19.7	31.6	34.2	37.2	37.8	40.8	48.7	49.6	65.5	1939
Valentia Observatory	13.2	18.9	24.1	35.5	41.0	43.7	53.1	70.5	115.7	1940

Next we come to inferential statistics by way of a question posed by the last table.

Looking at the 60-minute falls for 1960-1984 we see that a good many stations had maxima of 30 to 40 mm.

We know that falls of about 100 mm can occur.

But suppose that we are asked what hourly fall is likely to occur on average once in 100 years.

We have 25 years data from a set of stations.

Various (theoretically plausible ?) distributions have been proposed for extreme value analysis.

There are various methods of estimating the parameters of the chosen curve.

Can use a single station or some method of regionalisation.

Having estimated the parameters,the probability of any fall can be calculated.

What is the validity of such exercises?.

The uncertainty of the estimates of falls having a high return period is considerable.

Present-day scenarios for climate change raise further difficulties.

DROUGHTS

Definition:

15 or more consecutive days on none of which the rainfall is 0.2mm or more.

Over the period 1960-1984 the number of droughts ranged from 5-6 on the northwest coast to 24 near the sotheast and south coasts.

Occur mainly between February and October.

At Dublin Airport the longest drought during the period 1941-1984 was 30 days in August-September 1947,closely followed by a 29 day drought in July-August 1955.
However droughts were most frequent in Dublin in March-April.

RIVER FLOWS: EXISTING PRACTICE AND CLIMATE CHANGE

J. V. Martin Office of Public Works.

Introduction

Water enters the rivers through overland flow, interflow or groundwater flow. While the movement of individual molecules of water is an intriguing subject and has been the subject of many papers the main emphasis for the water resources manager is the resultant river flow or discharge.

The hydrograph of flows has two relatively distinct components:

- a slow annual or biannual movement, termed baseflow, resulting from groundwater flow.
- a more pronounced peaky rise and fall, termed effective runoff, where the river is reacting to rainfall.

Data collection

Direct collection of stream flow data involves the measurement of water level and stream discharge. Water level records are obtained by systematic observations on a manual gauge or from an automatic recorder. Measurements of discharge are made to define the flow/level relationship which is used in computing a continuous record of stream flow.

The Office of Public Works hydrometric service was commissioned in 1939 on the recommendation of the Browne Drainage Commission in an interim report to government. The type of gauge then installed consisted of a graduated staff which was read at a fixed time each day usually at 9 a.m. to coincide with the time at which daily rainfall gauges were read. In the early 50's a programme to replace these daily gauges with autographic gauges was instituted. Later, An Foras Forbartha through the Local Authorities set up complementary gauges and including the ESB gauges the national hydrometric network now comprises about 1200 gauging stations on rivers, lakes and tidal estuaries. Approximately 400 of these are automatic gauges.

The relationship between flow and water level at different stages of flow is obtained by measuring the velocity at a sufficient number of points at the gauging station to allow the mean velocity to be determined and is generally done using a current meter. Flow can also be measured by dilution, electromagnetic or ultrasonic methods.

The flow measurements for a particular gauge are plotted against the corresponding mean water levels on a suitable arithmitic scale. The array of points usually lies on a line termed a rating curve which is approximately parabolic. The logarithmic form of the rating curve may plot as a series of straight lines and changes of slopes, which correspond to changes in controls, can be seen more clearly.

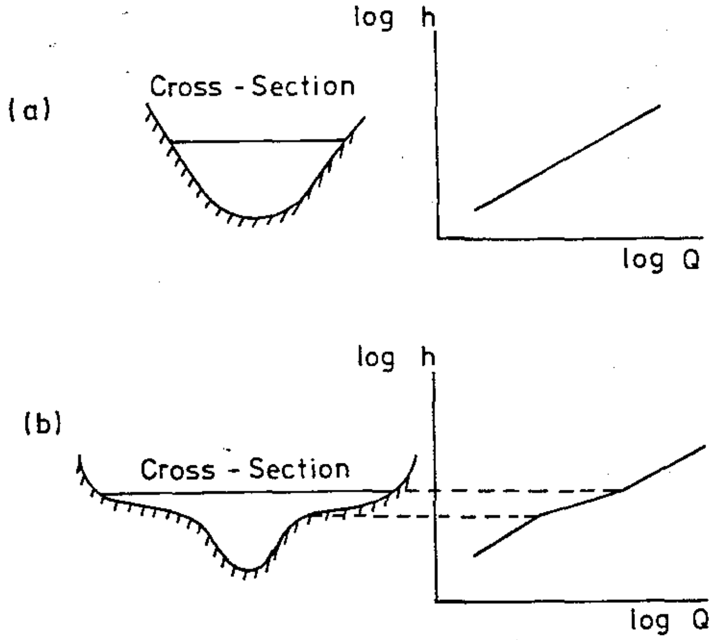


Fig. 1 (a) A simple control and the corresponding one-segment rating curve plotted on log-log paper, (b) A control with a marked change in features with height and the corresponding three-segment rating curve.

The flow - water level relation at the gauging site is controlled by the characteristics of the channel downstream. Rock outcrops, gravel bars, rapids or waterfalls can form a natural control that causes the relation to be stable in the low to median flow range. While each gauging site is selected with a view to ensuring, as far as possible, a unique and stable discharge - water level relationship this relationship can, and frequently does, vary with time due to temporary or permanaent changes in the river channel downstream (recent examination of a sample number of gauge records show that for a given volume of flow weater levels were generally 150 mm - 225 mm higher in recent years than they were some 30 years ago).

Low dams and weirs may be constructed across the channel to provide an artificial section control. Although laboratory ratings are developed for dams and weirs it is seldom desirable to use such a formula alone. The rating for each station should always be checked by flow measurement.

For low discharges in an open channel there may be only a minor variation in level for a relatively significant variation in discharge and hence measurement of low flows may not be very precise in these circumstances. To overcome this problem especially shaped weirs - crump type vee weirs - have been constructed in areas where determination of low flows is of particular importance. For very low discharges the flow is concentrated near the centre of the weir and both water level and discharge can be accurately determined. When the water level rises the weir is drowned out fairly easily so that at medium to high flows the weir has no effect on flow upstream.

The conversion of autographic record into a record of flow is automated and computerised. A digitiser is used to convert the water level record to digital form. This is then operated upon to yield various measures of flow - mean daily, monthly and annual discharges. Flood and low flow statistics and duration curves are produced as a matter of course.

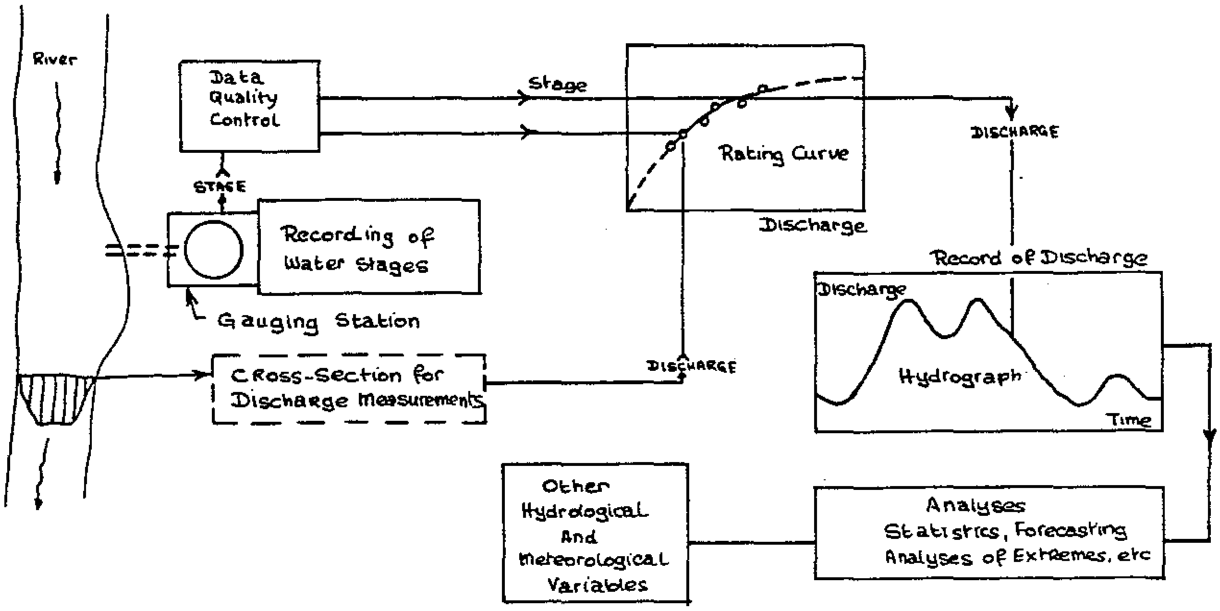


Fig. 2 Illustration of the conversion of recorded water stages into a record of discharge, providing the basic data for further hydrological analyses.

Analysis

Many uses are made of flow records and various indices and estimation methods are used in analysis. Some of those generally examined are: - Mean flow from total record; Mean flow from individual year; Annual maximum series; Peaks over Threshold series; Flow duration curve; Frequency distributions of flood and low flows; Series of annual minimum flows; Low flow spells; Minimum 7 day flows; Minimum 30 day flows; Drought Volumes; Time Series Analysis.

Combinations of these indices and methods of estimation are used to analyse the flow records, calulate floods and droughts of varying return period and to estimate or predict future flows or events.

Estimates of flows for ungauged catchments have been made using various catchment characteristics eg. area, stream length, slope, soil, and geological indices ect. but the "best" of the resultant formulae are equivalent to estimates from approximately one years record of data.

It is therefore well worth while installing a gauge at any location where development is being considered as the lead time for most major projects is larger than a year.

Future Climate Change and possible effects

Hydrologists and water resources engineers have, for long, used climate data for, among other things, water balance estimation, design flood calculations and hydrological forecasting and until recently no notion of change entered into those applications. Now a new dimension has entered into the way hydrologists think about climate: The acceptance that the past is an unerring guide to the future has been largely discarded. The reason for this change is the greenhouse effect, global warming, sea level rise and consequential climate change.

The World Meterological Organisation (W.M.O.) convened an international conference on the "Assessment of the Role of CO and other Greenhouse Gasses in Climate Variations and Associated Impacts" at Villach (October 1985) and WMO Report No. 661 summarises the outcome as follows:-

"The 2 x CO_2 case could be reached by 2030 and according to experiments with various climate models the values of the air temperature and the precipitation in Europe could significantly differ from that prevailing nowadays. Simulations with General Circulation Models (G.C.M.'s) point to the following:-

- higher temperatures in all seasons with a greater warming in winter than in summer.
- the rise in temperature will be sharper in high latitudes than in low.
- enhanced precipitation in Europe.
- uncertainties as to the geographical and seasonal distribution of the increases in pecipitation."

At a recent conference in Helsinki (1) it was generally agreed by the participants that the models being used at present are crude, of low resolution and make many assumptions, which are necessary to allow the studies to proceed but for all their limitations they provide an insight into the likely primary climatic impacts particularly temperature. These models generally indicate:

- doubling of CO_2 between 2030 and 2080
- estimates of temperature rise of between 1.5°C and 5.5°C
- increases in the sea level in the period to 2050 by 0.2m to 1.5 m
- changing rainfall pattern with increased rainfall intensity in Northern Europe.

The effects of such scenarios with the increase in sea level and changed rainfall pattern could be as follows:

River Flows

A recent study (2) for England has shown that runoff is very susceptible to change in rainfall and that increased rainfall would cause much larger flows. Monthly flows tended to increase as rainfall increased and relatively higher increases in winter lead to increased seasonality in flow.

Because of the increase in flood frequency peaks people and goods in settlements along the watercourses will be endangered by floods to a higher extent than today. Additional flood control projects to modify peak flows and augment low flows in certain catchments will have to be developed and existing schemes will have to be updated. The higher flows will lead to erosion, higher sediment transport, quicker deterioration and the necessity for more river works. As noted earlier some evidence of deterioration and silting of rivers has been found recently and this at gauging sites that that have been selected for their stability.

The methods of flood and low flow analysis will have to be adapted to the changing circumstances. Return period estimates may have to be re-examined. Careful analysis of gauge locations will have to be made and new gauges may have to be installed at areas that may be at risk in the future.

Increased sea levels

The effect of the sea level changes was highlighed recently in the New Civil Engineer (4.1.90) where it was stated that many low lying coral atolls in the Pacific and Indian oceans could disappear. A rise of 1 m in sea levels would inundate 16% of Bangladesh displacing over 10 million people. In total a 1 m rise in sea levels would affect 4 million km^2 , 3% of the earths land surface but a disastrous 1/3 of all cropland.

In Ireland the ports and coastal regions will be at risk from increased sea levels. The combined effect of high sea levels and greater flows could exaccerbate the flooding of coastal towns and the backwater effect could reach far upstream of the outfalls. The boundary between freshwater and sea water will be shifted further inland and water supply plants in such regions may be affected.

Other

Other areas likely to be affected are:

Town drainage systems where increased rainfall added to the increasing tendency towards urbanisation could overextend existing systems;

Inland waterways where supply of adequate water is critical. Energy supply from hydropower, Industry where large amounts of water are required for cooling processes.

Agriculture where changes in rainfall and river flows will affect the soil conditions.

Pollution control where changed flows will affect dispersion.

International Co-operation

The seriousness with which the world is now taking the threat is seen from the emphasis being placed on studies and programmes for the next few years by the World Meterological Organisation (WMO) through its operational hydrology programme and UNESCO through its International Hydrological Programme (IHP). The IHP has a number of programmes on climate variability and expected and the resultant effects on the hydrological cycle. Teams of experts from member countries will be analysing records and models, organising symposia and conferences and diseminating information through conference producing and the UNESCO Technical Documents in Hydrology series. There should be a clearer picture of the trends for the future at the completion of the programme in 1995.

Conclusion

The current hydrological data sets are large enough to indicate high runoff in the 40's and 50's less in the 70's and a tendency towards high runoff in the late 80's. OPW are currently examining the long term means and moving averages for some long records. Whether these will be long enough to indicate trends is still uncertain but the records over the next decade will be crucial in determining if such trends are occurring. It will be difficult to discern between a long term trend, long term seasonality or natural variations.

While waiting for final confirmation we should now start to prepare for a changing future. Our data recording systems for river and rainfall data and sea level and temperature monitoring must be maintained and upgraded as it is these that will give the first indications of the real effect of climate change. Our meteorologists, hydrologists and water resources engineers must be rigorous in their analysis and eventually provide reliable predictions which will add another dimension to the already complex project analysis and risk evaluation.

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POTENTIAL EFFECTS OF CLIMATIC EXTREMES ON RIVER AND LAKE QUALITY

Martin L. McGarrigle, Environmental Research Unit, Castlebar, Co. Mayo.

INTRODUCTION

The increase in 'greenhouse gases'

If the Earth's atmosphere were composed entirely of molecular nitrogen and oxygen the average surface temperature of the Earth would be 255°K. In fact, we observe a temperature of 288°K. The reason for this 33° difference is the presence in the atmosphere of a range of other heat-absorbing 'greenhouse gases' which trap heat in much the same way as the glass walls of a greenhouse. Carbon dioxide, methane, nitrous oxide, ozone, water vapour and CFCs are the primary greenhouse gases. Since the beginning of the industrial revolution atmospheric carbon dioxide levels have increased from 280 ppm to over 345 ppm today, with levels increasing from 315 to 345 ppm in the period 1958 to 1986 alone. This undisputed rise is almost definitely anthropogenic in origin.

To date there is no consensus on the manner in which this increase will affect local or global climate. Models of ever greater complexity are being constructed in an attempt to predict the outcome. An overall increase in global temperature seems to be an inescapable consequence of our present actions - whether this is 0.5°C or 2.0°C over the next number of years depends on the assumptions made and the model being used. Predicting the outcome on a regional basis may be very difficult because of the possibility that we are dealing with chaotic systems which are inherently unpredictable and extremely sensitive to initial conditions and random events.

Whether the detailed outcome can be modelled or not, we can rely on an ecological principle or axiom which states that if you put pressure on an ecosystem by steadily increasing an anthropogenic input to that system it will eventually collapse or, at least, show dramatic adverse effects. Here, we are dealing with the global ecosystem and the adverse effects may range from widespread dramatic storms, flooding, drought and famine, melting icebergs to fish kills or any of a wide range of other proposed results of global warming. Thus, the lack of precise predictions should not be seen as an excuse for inactivity by politicians and administrators in advance of a collapse. Action should be taken now to reduce the ever-increasing outputs of greenhouse gases.

Climate change and water quality

In order to provide a framework for discussing this topic, in spite of the difficulty of making predictions, we have to make some attempt at guessing how the increasing levels of greenhouse gases and the consequent additional thermal energy in the atmosphere will affect our surface water resources. One of the most popular predictions is that the hydrological cycle may tend towards greater extremes - with more intense rainfall and flooding during the winter and less rainfall during the summer months - but with higher average temperatures across the seasons. Indeed, the dry summer of 1989 followed by a mild but extremely windy winter may be an example of a typical year of Irish 'greenhouse effect' weather. However, it is obvious that it is impossible to blame one particular year's weather on the greenhouse effect rather than on normal climatic fluctuations.

LOW FLOWS AND HIGH TEMPERATURES IN SUMMER

The combination of summer drought and higher water temperatures is perhaps a worst-case scenario from the point of view of water quality in Ireland. This scenario will be discussed under a number of headings relevant to water quality.

Effluent dilution capacity

The assimilative capacity of rivers is dependent on available dilution during the driest time of the year. In licensing effluent discharges low flows are critical, whether they are calculated as 7 day low flows, 95 percentile flows or by other statistic of low flow. The water quality management plans for major catchments set quality criteria for pollution levels in rivers. In the case of an organic effluent it might be required to maintain downstream BOD levels at or below 3 mg/l after the effluent is completely mixed with the river, even at the time of lowest flow. Mass balancing is carried out using the mass balance formula for the flows at critical dry periods:

$$\text{downstream BOD} = \frac{cf + CF}{f + F}$$

where c and C are the concentrations of BOD in the effluent and the river respectively and f and F are the flow rates in the effluent and river respectively. Effluent flow and concentration are regulated until the downstream BOD value meets the required standard at low flow. It is apparent that a reduction in minimum flow will reduce the river's ability to assimilate organic effluents. If historical estimates of minimum flow rates are now too high because of progressive global warming then the basis for effluent controls will be in error and, hence, our ability to regulate river pollution by means of this device. Similarly it is apparent that all unlicensed effluents and accidental spillage of pollutants will have a more severe impact on water quality if flows are reduced.

Eutrophication and Dissolved Oxygen levels

Increasingly, eutrophication is becoming a problem in Irish rivers. Eutrophication results from the increased artificial fertilisation of surface waters leading to greater plant and algal growth. Increased biomass of plant and algal material results in higher respiration levels which can cause critically low dissolved oxygen (DO) levels during the hours of darkness. Almost 50 percent of fish kills are now due to this type of effect (Moriarty 1990).

Lower river flows in summer imply higher nutrient concentrations, even if present nutrient runoff amounts are assumed not to change. Present records show a definite inverse correlation between phosphate concentration and river flow rate (Toner and McGarrigle, 1989). Higher average water temperatures may be expected to increase plant and algal growth rates and standing biomass crops. Plant and algal respiration rates are also temperature-dependent and these increase as temperature rises. Biological respiration of benthic mud and of suspended organic matter also proceeds at a faster rate at higher temperatures. Lower summer rainfall could also lead to an effective increase in water temperature as the cooling effect of frequent rain would be lacking. Lower rainfall may also lead to warming of source springs for rivers. Reduction in water velocity due to lower rainfall may also be expected to cause a further increase in the amount of algae and rooted macrophyte vegetation present in river channels. The rate of water-atmosphere interchange of oxygen increases with temperature. Thus, equilibrium with the atmosphere is reached more quickly in warm waters. This effect will act against the impact of most of the other phenomenon cited above.

<u>Modelling of DO in relation to temperature</u>

It can be seen that prediction of the impact of eutrophication on DO levels in rivers is not as easy as mass balancing of BOD and other effluent parameters. Computer modelling is required to carry out the calculations, due to the large number of parameters which affect DO levels. The ERU River Water Quality Model attempts to produce such predictions (McGarrigle, 1984). It has been calibrated for a number of different river types and gives reasonably realistic predictions. This deterministic, plug flow, river model comprises some 20 equations describing the principal processes which affect DO levels. Five of these are treated as temperature-dependent in the model: physical 'reaeration', BOD decay, photosynthesis, plant and algal respiration and mud respiration. In addition, the overall plant and algal biomass (treated as an input in the model and not modelled directly in relation to temperature) will be strongly temperature dependent. The model was used to simulate temperature increases from 18°C to 22°C in simple, river channels. These simulations appeared to indicate that DO levels have a degree of resilience in the face of temperature change when all other parameters are held constant. For a 5 m wide channel of depth 0.2 m, velocity 0.1 m s^{-1} and constant plant biomass of 100 g m^{-2}, a decrease of only 2 percent in minimum oxygen saturation levels was obtained during darkness as temperature was increased from 18 to 22°C. A larger drop in DO had been expected and it is assumed that increased rearation rates were the primary compensating factor. It must be borne in mind however, that pollutant concentrations, flow velocity, water depth, and plant biomass would all be dramatically affected in warm dry summers. Thus, in the worst-case scenario for river quality they would act in a synergistic manner and must inevitably cause more serious reductions in minimum DO levels than those modelled here.

In summary, this warm dry summer scenario predicts a number of simultaneous adverse consequences for rivers: lower flows resulting in less dilution for effluents, greater difficulty in predicting low flows accurately and arriving at realistic licence conditions, higher nutrient concentrations due to lower flows, greater plant and algal growth in response to warmer temperatures and nutrient concentrations, higher respiration rates in response to higher temperatures, less rainfall contributing to higher water temperatures and lower flow velocity. Thus, any future increase in temperature will accentuate any existing or future water pollution problems.

Thermal Regime in lakes

The thermal regime of a lake is important in determining a lake's response to enrichment. In particular, it is important to know whether a lake undergoes thermal stratification during the summer. Changes in mean summer temperatures and wind speeds could have significant effects on the status of many of Ireland's lakes. Pollution of lakes in Ireland is generally accompanied by a change in trophic status from oligotrophic (nutrient poor), through mesotrophic, to eutrophic (nutrient rich). Higher trophic status lakes produce larger crops of algal biomass.

Lakes in Ireland are unusual in the European context in that they are generally capable of supporting large stocks of brown trout (*Salmo trutta* L.). The mesotrophic limestone midland and western lakes provide very good feeding for trout. Growth and survival are much better than in the usual lake habitat for trout in Europe, which is in oligotrophic mountain lakes where growth is poor. The western and midland lakes are generally well-mixed due to relatively continuous winds all year round. The continuous mixing of lake water provides relatively cool, well-oxygenated water suitable for trout even in summer.

Prolonged thermal stratification is not a common occurrence at present in Irish lakes except in some deep, sheltered lakes. However, if higher temperatures and reduced wind speeds were to become the norm during the summer then stratification could become commonplace even in relatively shallow lakes. Stratified lakes form definite thermoclines during the summer months, separating the water into a warm top layer and a cold bottom layer which do not mix throughout the summer months. The upper layer, or epilimnion, may reach temperatures of over 20°C whereas the lower hypolimnion can remain at 8 to 10°C until overturn in the autumn when increasing wind speeds provide sufficient energy remix the layers. Serious hypolimnetic oxygen depletion may occur in the isolated bottom layer of a stratified lake because there is no replacement for oxygen consumed in the hypolimnion. Thus, mesotrophic and eutrophic lakes which stratify and undergo oxygen depletion may become unsuitable for oxygen-sensitive species such as trout once epilimnion temperatures rise above 20°C. The possibility of trout finding refuge in a well-oxygenated and cool hypolimnion is excluded because there is insufficient oxygen there. Oligotrophic lakes which stratify do not undergo significant oxygen depletion in the hypolimnion. However, many of the important amenity lakes in Ireland are classed as mesotrophic and oxygen depletion would be likely in the event of prolonged summer-long stratification.

Eutrophication of lakes

Many of the comments concerning the impact of rising temperatures on eutrophication in rivers will apply equally to the eutrophication of lakes - we might expect increased phytoplankton crops and resulting problems from nuisance blooms. Again, any existing water quality problems will be accentuated by rising temperatures whether thermal stratification occurs or not. Accelerated infilling of very shallow lakes by increased production of littoral and marginal vegetation is also a possible outcome of increasing temperatures.

Possible impacts on fish and invertebrate life

In Ireland, salmonid fish are important from the point of view of the angling industry and tourism. Their importance is recognised in the fact that water quality management plans use guidelines for salmonid fish as the basic criteria for setting water quality standards (Toner pers. comm). Higher water temperatures cause increased metabolic rates in all aquatic invertebrates and fish. Thus, in species with a high demand for oxygen, such as the salmonid fish and oxygen-sensitive insects such as stoneflies, problems may arise as the absolute amount of dissolved oxygen present in water decreases with increasing temperature. In the warm summer of 1989 a number of fish kills were attributed simply to warm conditions and low flows rather than pollution *per se* (Moriarty, 1990). Salmonid fish such as salmon and brown trout are cold water species. The optimum temperature for growth in adequately fed brown trout (*Salmo trutta* L.) is 13°C and growth is adversely affected if daily mean values greater than this occur (Elliot 1975). Survival becomes increasingly difficult if temperatures remain above 20°C for extended periods. 25°C is regarded as the lethal temperature for trout. Ricker (1934) regarded maximum temperatures of 24°C as the upper limit for trout in his river classification system. At high temperatures, any drop below 100 percent saturation results in reduced activity in trout (Hynes 1970).

Table 1. Maximum temperatures °C at 1401 Irish river stations (1983-1985).

No. Stations:	1	7	13	40	82	99	148	238	251	212	134	83	33	25	35
Temperature	11-	12	13	14	15	16	17	18	19	20	21	22	23	24	25+

Spot water temperature measurements made at some 1400 Irish river stations over the period 1983 to 1985 show that maximum temperatures of 24°C or over were recorded at 60 stations, some

4.3 percent of stations (from data in Flanagan and Larkin, 1986). Table 1 shows maximum recorded temperatures at all stations grouped in 1 degree intervals. If maximum water temperatures were to increase by one or two degrees it can be seen that salmonid fish would come under increasing stress due to low DO levels and high temperatures. It might be expected that stretches of many rivers where temperatures regularly exceeded 24 to 25°C could become unsuitable for trout and salmon parr, at least during the summer months.

WINTER CONDITIONS

The initial hypothesis included the possibility of increased rainfall during the winter and little has been said about this. Flash floods, increased erosion and instability and/or silting of gravel beds used for spawning may be important considerations during the winter months (O'Grady, pers. comm.). Giller *et al.* (1990) have shown that severe floods can cause long term reductions in invertebrate density in Irish rivers. Winter temperatures and conditions in spring when eggs hatch may also be critical for long term survival of trout and salmon in Ireland. Increased suspended solid load and water coloration may also become an increasing problem at water abstraction sites during the winter months.

THE 12th CENTURY WARM PERIOD

The historical record may give us an idea of what may result from the greenhouse effect. During the late 12th Century at a time when average annual temperatures in Ireland were 2°C higher than at present - the chronicler Giraldius Cambrensis (as quoted by Mitchell, 1986) tells us that:

> 'Ireland is the most temperate of all countries. Snow is seldom, and lasts for only a short time. There is a plentiful supply of rain, such an ever-present overhanging of clouds and fog, that summer scarcely gives three consecutive days of really fine weather. Winds are moderate and not too strong.... The country enjoys the freshness and mildness of spring almost all year round. The grass is green in the fields in winter just the same as in summer. Consequently, the meadows are not cut for fodder, and stalls are never built for the beasts.'

However, wheat did not ripen and was difficult to harvest...

> 'because of the unceasing rain. For this country more than any other suffers from storms of wind and rain.'

It appears that 12th Century Ireland, while somewhat warmer than today, did not suffer from particularly dry summers. This may be some consolation to water quality managers. There is also some consolation with respect to the ability of salmonid fish to survive higher temperatures than those prevalent today: Giraldius also reports that trout and salmon, eels and lampreys were plentiful in Irish rivers and streams but that they lacked coarse fish. Paleoclimate research may give us a better indication of what the future holds in store.

CONCLUSIONS

From the point of view of water quality management what is needed most at the moment are long term baseline data by which any future changes can be gauged. Seasonal and year to year variations are considerable in all biological systems. Existing pollution levels, fish stocks, patterns of macrophyte and algal growth in our rivers and lakes must all be quantified. Lakes in particular have been neglected somewhat due to logistic problems. More research is needed on river eutrophication under existing conditions. Licensing authorities under the current Water Pollution Act may have to be somewhat more cautious in setting licence limits based on predicted low flow patterns in rivers - there have been a number of record 'low flow' years in the past 15 years. The worst-case scenario presented here suggests that a trend towards warmer summers will aggravate any existing pollution problems. Thus, a policy which aims to eliminate all current pollution may be the best approach for dealing with any future climate change from the point of view of water quality.

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THE LIKELY EFFECTS OF SIGNIFICANT CLIMATIC CHANGES ON THE FLOW REGIME IN THE PRINCIPAL IRISH AQUIFERS.

Eugene P. Daly - Geological Survey.

I. INTRODUCTION:

Geological strata can be divided into two groups: AQUIFERS, those strata that consistently yield significant amounts of groundwater and AQUITARDS, those that do not.

The principal aquifers in Ireland belong to one of seven lithological categories and they cover over 25% of the Island.

Four hydrogeological characteristics are central to the discussion of this topic in an Irish context. Also of importance is whether or not the negative factors of low storage and rapid throughput (permeability) are balanced by additional storage in the unconsolidated deposits and the fairly consistent recharge which occurs for a considerable part of the year. The principal characteristics of the aquifers in Ireland are given in Appendix A.

In volume terms the throughput is greatest (therefore contribution to baseflow) in the limestones (especially karstified) and the sands and gravels. Groundwater resource and baseflow measurements show that throughput as a proportion of potential recharge is greatest in the aquifers of the south and southeast. This confirms the view that the storage in the limestone aquifers in these areas is higher than elsewhere owing to the greater depth of karstification.

II. HYDROLOGIC CYCLE:

We are concerned here mainly with that part of the cycle that begins at the land surface and ends at the ocean. We look at that part of precipitation (potential recharge) that;

(a) flows directly overland to rivers,
(b) flows rapidly at shallow levels to streams/rivers and frequently emerges as ephemeral springs,
(c) flows deeper underground for a variable period before re-emerging either directly or via permanent springs into streams/rivers or the sea.

The proportions that follow the different paths are largely a function of the geology.

The influence of climate on this part of the cycle, its response and the mechanisms of recharge and discharge are best illustrated with the aid of river and well hydrographs (Figure I). The response of most aquifers to recharge depends largely on the geology, topography and hydraulic conditions. In the geological strata in Ireland there are essentially six types of hydraulic conditions which describe most hydrogeological situations.

In Ireland most groundwater flow occurs at relatively shallow levels (less than 100m) and along short flow paths.

III. SEASONAL WATER LEVELS:

At the end of the summer both river and groundwater levels are at their lowest. The combination of increased rainfall and lower evapotranspiration initially results in an increase in riverflow which subsequently is followed by a rise in groundwater levels due to direct recharge. In normal circumstances winter groundwater levels are reached quite quickly (within a month). Peak levels are usually reached sometime between November and March. The reduction in rainfall amounts and increase in evapotranspiration in the spring results in a decrease in groundwater levels. The groundwater recession continues to the end of the summer. In some years the recession is interrupted and in other years it is not.

Certain parts of the two main aquifer types (karstified limestones and sands and gravels) also receive additional recharge (indirect) from sinking streams and shallow groundwater flow in the aquitards. The variation in the amount follows the same pattern as that described for direct recharge.

In Ireland the two extreme positions occur in the northwest where recharge is probably greatest and in the southeast where it is the least. Well hydrographs in the two areas show that water levels are generally higher, the groundwater recession shorter and the interruptions in the recession more frequent in the northwest. In the southeast the groundwater recession ranges from three to seven months and averages about five months whereas in the northwest it varies from 1-4 months.

There is very little historical groundwater level data available. A number of well hydrographs are available for the east and southeast since the late 60's and the early seventies. In the southeast minimum groundwater levels were recorded in seven years in the 70's and only three years in the 80's. In this area the seventies were at the end of a period of slightly drier weather than in the first half of the century. A similar dry period occurred at the end of the last century.

The depth of karstification in the south suggests that water levels may have been much lower around the time of the Ice Age.

IV. GROUNDWATER THROUGHPUT:

Groundwater throughput is the volume of water moving through an aquifer (or part of). In the summer it is particularly important as it is the source of lowflow in rivers. The throughput in any aquifer/aquitard is a function of the amount of recharge which the strata can retain and the permeability, storage and hydraulic conditions which obtain in that particular area.

Some strata are unable to retain, for any significant time period, all the recharge which is available to them. Hence the recharge is said to be rejected. A significant amount (up to 50% in some cases) of available recharge is rejected by most aquitards, the lowlying/discharge parts of many aquifers and the karst limestones.

The type of hydrograph, the rate of decline of the recession and a knowledge of the hydrogeology gives a good indication of the throughput. Rounded hydrographs with a gradual recession indicate large and sustained throughput whereas hydrographs with numerous peaks and a sharp recession indicate little throughput to baseflow in the summer. In the wetter parts of the country this lack of long term storage related throughput is often balanced by the longer recharge period and more frequent interruptions in the groundwater recession.

At the end of a long recession the rate of decrease of the recession curve tapers off and in time (if no recharge occurs) would become zero. At this level the aquifer (or part of) is unable to discharge naturally and the reserves in "live" storage are depleated. However the reserves in "dead" storage below this level are still available for artificial development (pumping).

Very low groundwater throughput in an aquifer at the end of the summer period can result from (1) a normal winter recharge period being followed by a very long recession or when a winter period with very low recharge is followed by a normal recession. Low groundwater throughput will only have a noticeable effect on riverflow if it occurs at the end of a summer with below normal rainfall (e.g. 1978 in the southeast). If a winter recharge period did not take place and was followed by a normal recession the effect on lowflow in most rivers would be very serious.

V. DISCUSSION:

At the end of the winter recharge period most aquifers are full (overflowing?) and hence can provide substantial baseflow to rivers during the spring and summer. In the west the low and shallow storage (and rapid throughput in places) of the geological strata is compensated by a normally short groundwater recession and in some areas by storage in Quaternary deposits and bogs. In the southeast/south where the recession (non-recharge period) is much longer the rock storage extends deeper and additional storage is provided by the Quaternary deposits. In the prevailing climatic conditions the following are the areas where lowflows come under stress in extended dry periods i.e. areas underlain by aquitards (especially small upland catchments) east of a line from Belfast to Cork, small islands and areas of karst limestone. These are the areas which are dependent on summer rainfall to sustain lowflows and where low storage and rapid throughput are not balanced by storage in the Quaternary deposits. It is only in a limited number of instances where groundwater has been developed that very low water levels have any effect. These will be discussed below.

VI. IMPLICATIONS OF POSSIBLE CLIMATIC CHANGES:

The general consensus appears to be that the climate may get warmer and wetter. From the groundwater point of view in Ireland changes in the amount of rainfall are probably not as important as the way the rainfall is distributed throughout the year, assuming the areal variation remains roughly the same. Warmer and wetter summers are likely to result in a small increase in the soil moisture deficit at summer's end. Wetter winters will result in more rejected recharge, higher river/groundwater levels and a shorter non-recharge period. Even if rainfall amounts decreased slightly the impact on groundwater levels and throughput would be quite small.

The alternative most likely to have a significant negative impact on the groundwater system in Ireland is where warmer summers are combined with more seasonal rainfall i.e. where the same amount or increased rainfall would occur over the main recharge period and less rainfall in the spring (as suggested by McWilliams, Irish Times, 1990). This would result in longer,uninterrupted groundwater recessions.

Summer conditions in the west/northwest should be similar to what they are in the southeast under present conditions. The types of area (see Section V) now affected most severly in the east during extended dry periods are very common in the southwest, west and northwest. Lowflows in rivers in these areas would be much lower than at present and many permanent shallow springs and seeps would dry up mainly due to the lower storage available and rapid throughput.

In the east the conditions which now prevail in dry years should then become the norm. In these circumstances I think conjunctive use of groundwater and surface water might become more common.

The impact of lower groundwater throughput and levels (say $<$ 2m), at the end of the summer recession, on the abstraction of groundwater for use, will be quite small. It will mainly be water in the unconfined zone that will be affected. Abstractions of groundwater from the upper part of the "live" reserves will be affected the most i.e. shallow dug wells and infiltration galleries, boreholes whose producing zone is very close to the existing summer pumping level and intermediate and high level springs. Large lowlying springs and boreholes producing water from "dead" storage will be mainly unaffected.

VII. REFERENCES:

This lecture has been prepared mainly from data collected and reports prepared either entirely or in part by the Geological Survey.

This is the text of a lecture given at the I.A.H. meeting in Portlaoise, May, 1990. Additional figures were included in the lecture.

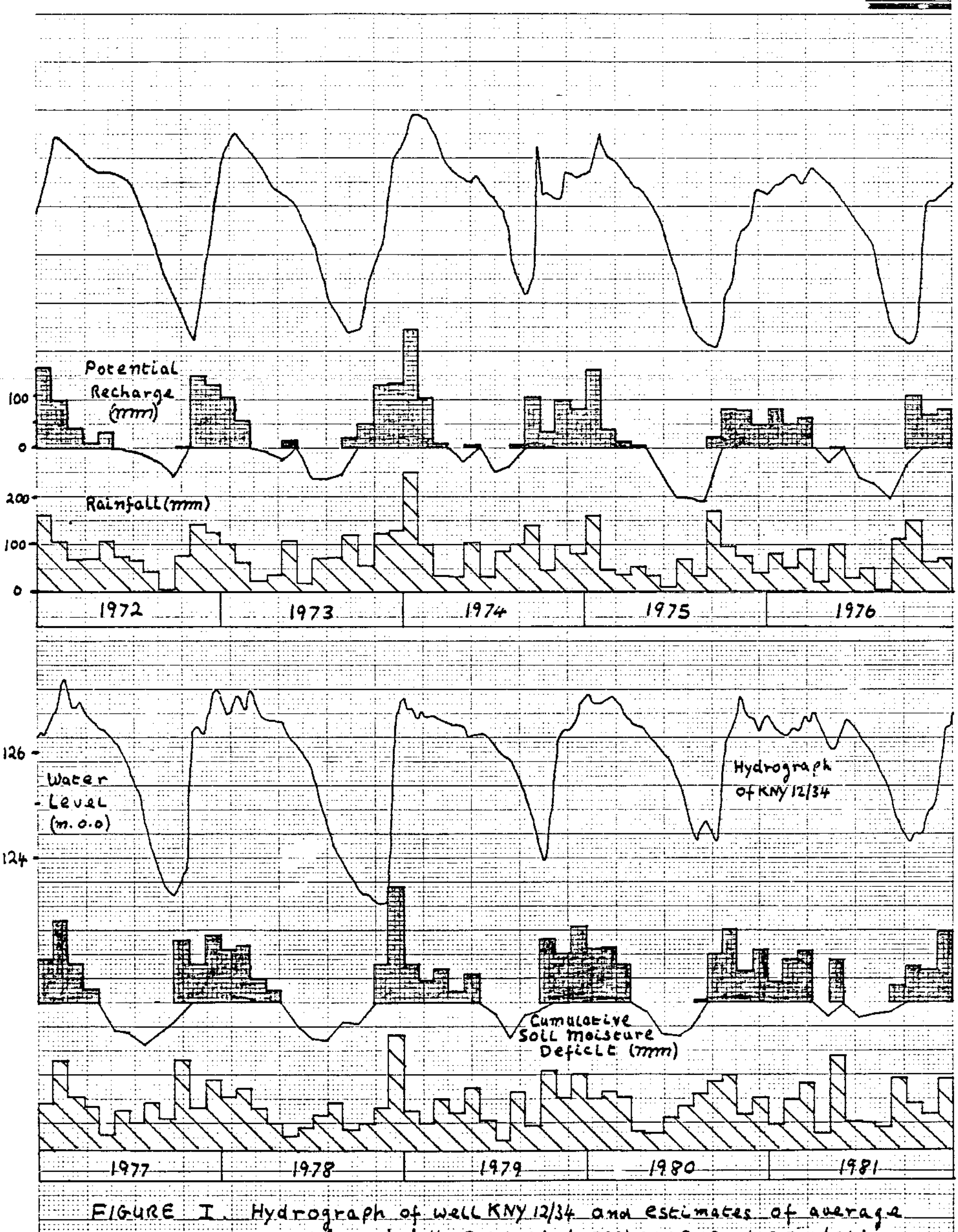

FIGURE I. Hydrograph of well KNY 12/34 and estimates of average monthly rainfall, potential recharge and cumulative soil moisture deficit over the Nore River Basin.

APPENDIX A: **Aquifers in Ireland**

Most of the aquifers in Ireland have a number of characteristics in common. They are:

(a) they have relatively low storage
(b) fissure flow predominates (except in the case of the Permo-Triassic sandstones and the Quaternary sands and gravels). Hence the permeability (transmissivity) is very variable and can be anomalously high along fault/fissure zones.
(c) the rock aquifers are overlain by Quaternary (unconsolidated) deposits whose lithology, thickness and permeability are very variable.
(d) all receive relatively large amounts of direct recharge (from rainfall) which occurs consistently between October and March. Recharge however can occur in any month even in the driest parts of the country. Many aquifers (especially the sands and gravels and the karstified limestones) receive a variable amount of indirect recharge throughout the year. As will be discussed elsewhere some of this potential recharge is actually rejected as the aquifer is already full.
(e) the hydraulic conditions are variable and can change over relatively short distances.
(f) in these aquifers the water levels are generally shallow (<10m), the annual fluctuation < 5m and they normally have steep gradients. Parts of the sands and gravels and the karstified and synclinal limestones being the only significant exceptions.

Some additional information on each aquifer is given in Table I.

The aquitards consists of many different rock types. However hydrogeologically they tend to behave similarly. Transmissivity and storage are low and what is there is generally restricted to the top 30m or is in fault/fissure zones. The water table is generally close to the surface (< 5m), the annual fluctuation is < 5m and the gradients normally steep. Unconfined conditions predominate. These strata, are usually full and do not accept much recharge. These are the areas which provide most of rapid runoff and hence are the principal source of flood flows in rivers.

Quaternary Sands and Gravels: Some extensive and thick aquifers, however they are generally narrow and relatively thin in river valleys. In the former the water table can be quite deep (>20m) with a relatively shallow gradient. The annual fluctuation in these aquifers is normally less than 2m. Parts of these aquifers are frequently recharged indirectly by shallow groundwater flow from aquitards with which they are in contact or by stream becoming influent as they pass over the deposit. These deposits also provide a mechanism for the discharge of rock aquifers via springs or through riverbeds. These aquifers are a major source of baseflow in Irish rivers.

Chalk: The throughput in this aquifer is thought to be quite rapid and does so via large springs at the contact of the base of the chalk and the underlying greensand.

Permo-Triassic Sandstones: Although underlying much of the northeast this aquifer only comes near the surface in a number of relatively small areas around the Antrim Plateau. Nevertheless it is probably the most intensively developed aquifer in this island. In the Lagan Valley flow is restricted by basalt intrusions.

Westphalian Sandstones: This aquifer consists of two main sandstone units and a number of minor ones. The throughput is very small and is significantly affected by the geological structure and the results of mining over the last 200 years. Transmissivity is much greater (up to $400m^3/d$) along zones.

Upper Visean Limestones: The most extensive rock aquifer with the largest throughput in the country. Hence it is a very important source of baseflow and frequently discharges via very large springs. Although extensively fissured close to ground level it is much reduced at depth. Furthermore the depth of fissuring appears to be greatest in the south and least in the north.

The water table (<5m - >100m), gradient (low to high) and annual fluctuation (1 - >30m) can all be very variable. Owing to the karstified nature of the aquifer they can be difficult to develop in places.

Visean "Calp" sandstones: may contain some intergranular flow. In north Monaghan and Armagh the aquifer is covered by drumlins which severely limits recharge.

Synclinal limestones: Intense folding in the region has resulted in all the limestone strata being strongly jointed. The cleaner limestones ("reef, dolomite and calcarenite") are probably the most productive. The overlying sands and gravels add considerably to the storage available in these aquifers. The water table can be up to 30m below ground and the annual fluctuation up to 12m.

Dolomitised Reef Limestone: possibly some intergranular permeability. Probably the one aquifer in Ireland in which significant flow is possible at depth (>300m).

Tournaisian (lower) Limestones: a sequence of thin bedded limestones, argillaceous limestones and shales. Evaporite lenses scattered randomly throughout the sequence appears to enhance the permeability.

Ordovician Volcanics: Interbedded with marine sediments. The volcanic material thins rapidly away from the vents. Intrusive dykes and sills frequently occur within the volcanic strata and therefore restrict groundwater movement.

More detailed information on these aquifers can be obtained in the previous proceedings of the Portlaoise meeting and in numerous reports and publications by the Geological Survey.

uifer Age	Lithology	Distribution	Topographic Setting	Quaternary Cover	Specific Yield	Trans-missivity m^2/d	Recharge Conditions	Hydraulic Regime
Quaternary	sand and gravel	widespread	generally lowlying	thin (<5m) alluvium or tills	0.05-0.15	20-2,000	high, takes a large % of effective rainfall.	mostly unconfined. Sometimes confined in river valleys.
etaceous	chalk	NE (Co. Antrim)	elevated around foothills of Antrim Plateau except at coast.	variable thickness and lithology.	<0.04	up to 300	low, mainly by leakage through overlying basalt limited outcrop area.	mostly confined, except for outcrop area.
rmo-riassic	sandstones	Lagan Valley, NW, W and SW of L. Neagh, Kingscourt.	normally lowlying.	generally thin except in river valleys where overlain by sand + gravel and west of L. Neagh where covered by drumlins.	up to 0.10	20-300	low, except at outcrop and where it is in contact with sand + gravel.	mostly confined. artesian in the Lagan Valley.
Carboniferous stphalian	sandstones	principal coalfields	mainly uplands	usually thin and impermeable.	0.01	5-20	low, owing to limited outcrop, type of cover, slope of land.	mainly confined.
Upper Visean	clean "Burren" type limestones.	widespread	lowlying but extending up into foothills.	usually thin but can be quite thick in small normally lowlying areas.	0.001-0.05	0.1-2,000	very high over large areas. also receives indirect recharge from sinking streams.	normally unconfined, karstified over extensive areas.
sean "Calp"	sandstones	the north and NW, W and Shannon Regions (⊥)	lowlying but occassionally elevated	normally relatively thin. In certain areas very thick (>30m drumlins).	0.01-0.03	20-200	low to medium.	unconfined at outcrop becomes confined within a short dist.
urnaisian Synclinal Limestones	"reef"/dolomitised "reef"/bedded limestones	South of Ireland	normally lowlying.	thin to thick (≤20m), over much of these aquifers it is quite permeable.	0.01-0.05	20-2,000	generally high.	mainly unconfined, in contact with sand + gravel, karstified in places.
Tournaisian	dolomitised "reef" limestone	southern half of the Central Plain	lowlying apart for some "reef" knolls.	mostly thin, permeability of cover varies from low (peat) to high (sand + gravel).	0.01-0.06	100-2,500	low to high.	generally unconfined over outcrop area.
urnaisian	limestones	NW Region and Co. Armagh	rolling hills (drumlins)	medium to very thick and impermeable.	0.005 0.03	50-500	generally low due to thick cover + impermeable soils.	normally confined.
urnaisian	sandstones	NW and E Regions	lowlying	medium to thick and impermeable.	< 0.02	100	low, due to cover + impermeable soils.	normally confined.
Devonian iltorcan ormation)	sandstones	SE, S and Shannon Regions	low to medium, foothills of Lr. Palaeozoic Inliers.	normally thin except for some of the lowlying ground.	0.01-0.05	20-1,800	low to medium.	unconfined at outcrop, becomes confined down-dip, frequently artesian.
dovician	volcanic tuffs and lavas	SE and E Regions	low to slightly elevated.	generally thin except for some river valleys	<0.02	15-500	medium, limited outcrop + impermeable soils.	mainly confined (by shales) except for outcrop areas.

TABLE I: Some details of the principal aquifers in Ireland.

(⊥) Water resource regions in Republic.

COPIES OF OVERHEADS

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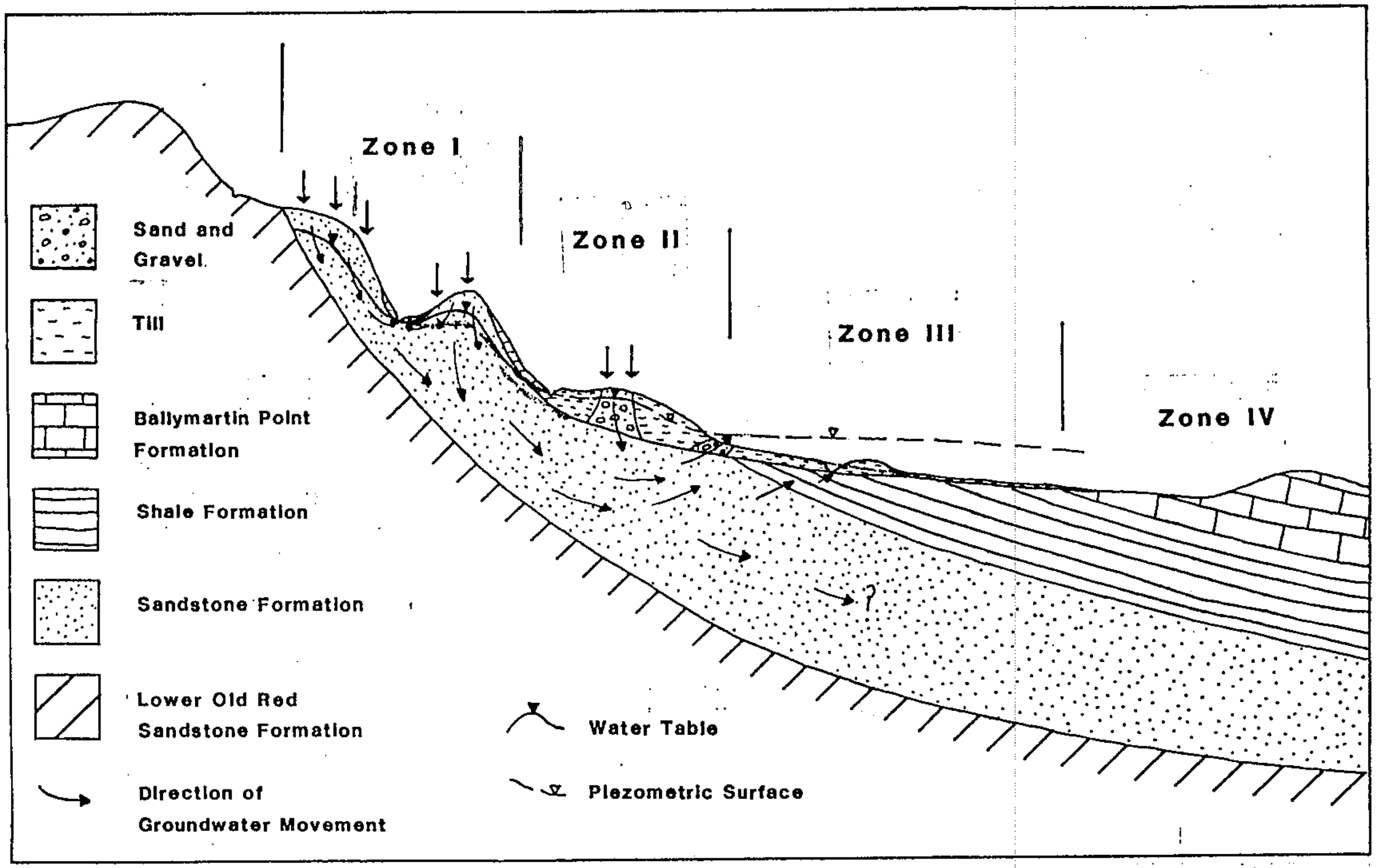
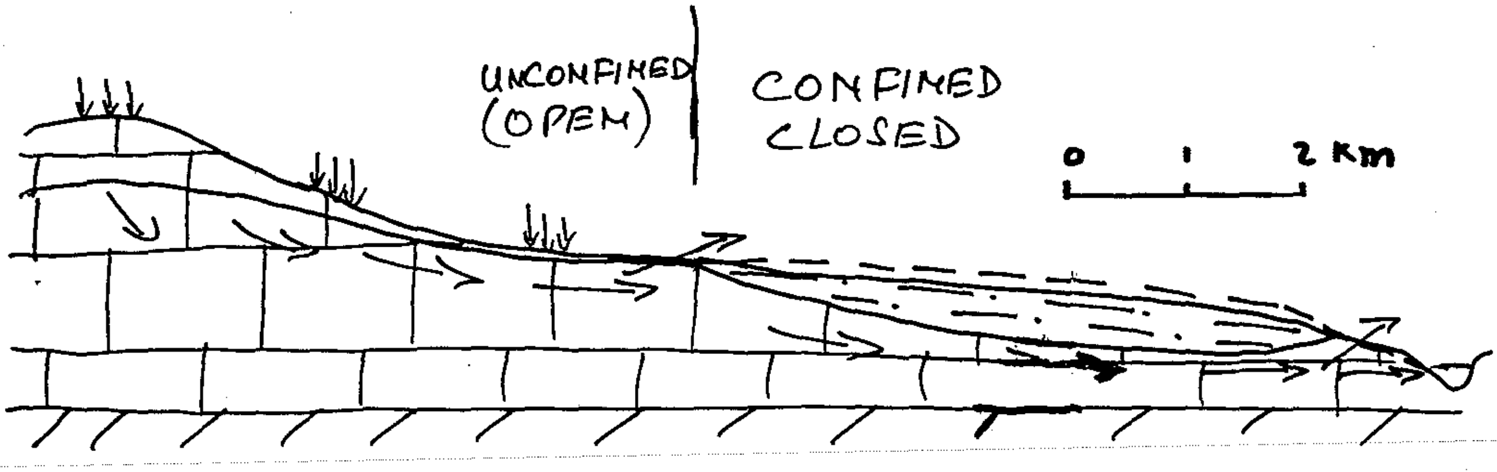
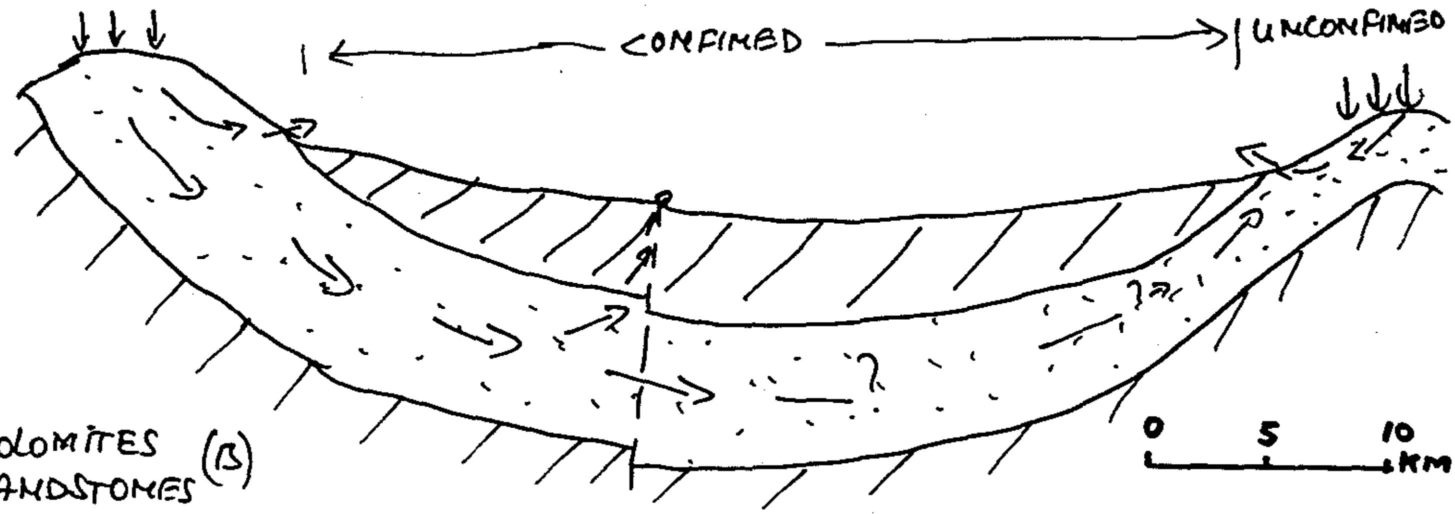


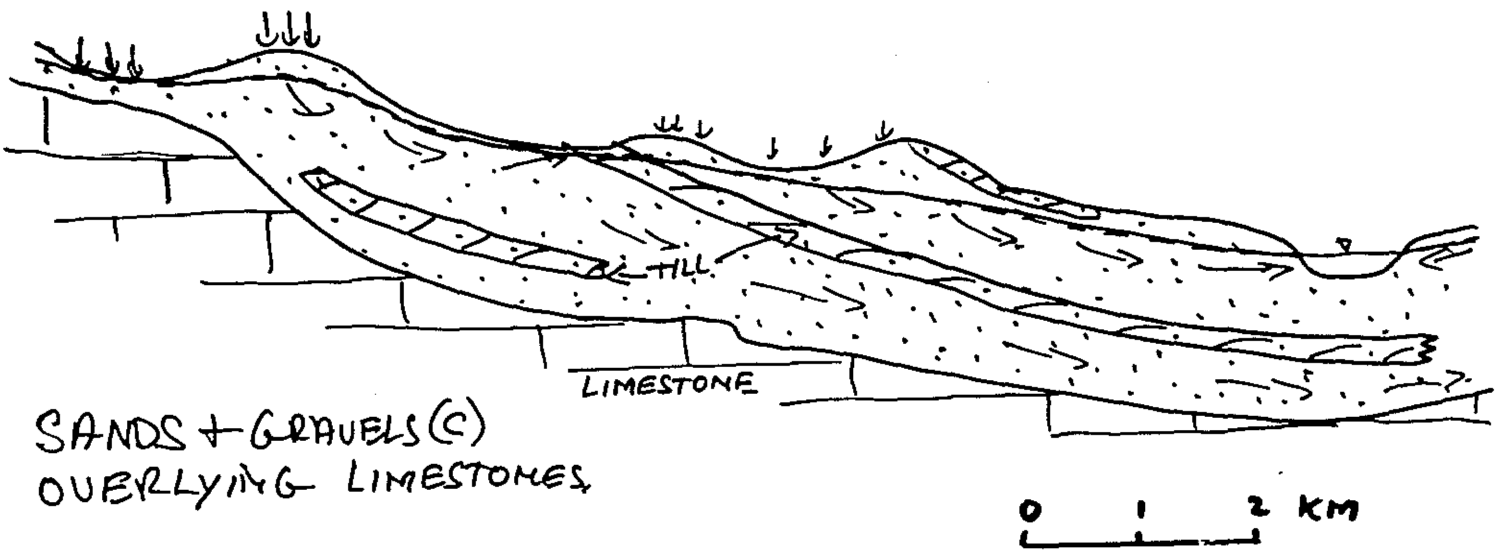
Figure V.2.12. Schematic representation of groundwater movement in the Kiltorcan Aquifer System

LIMESTONES (A)



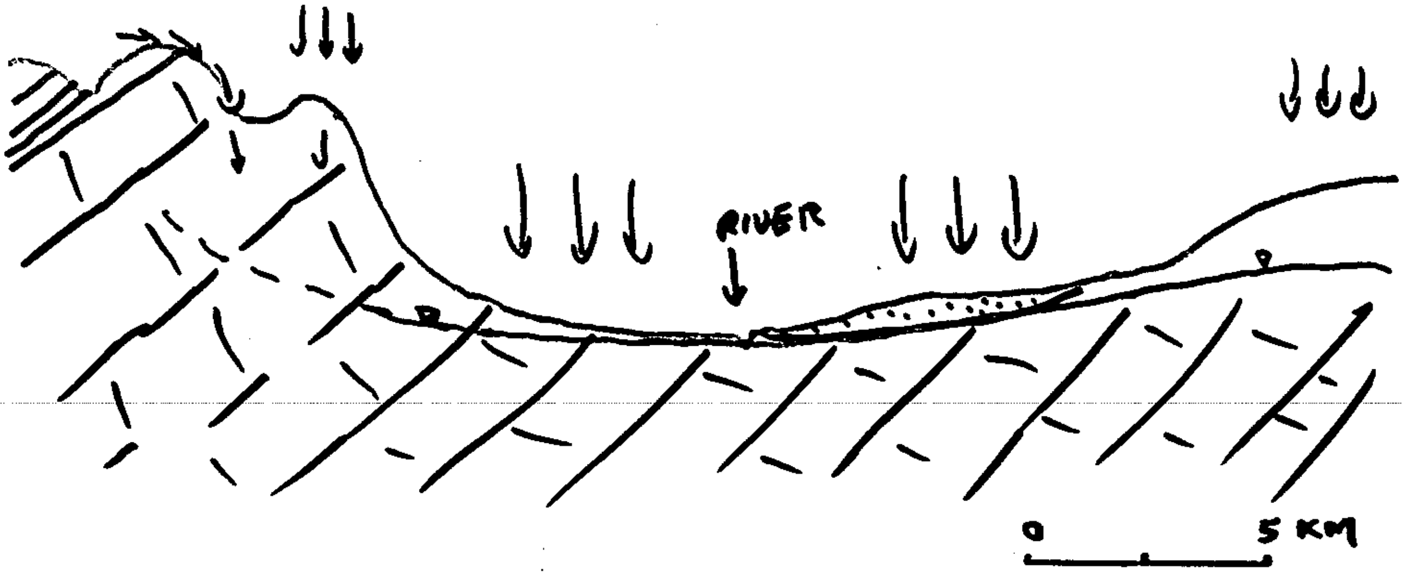


DOLOMITES SANDSTONES (B)

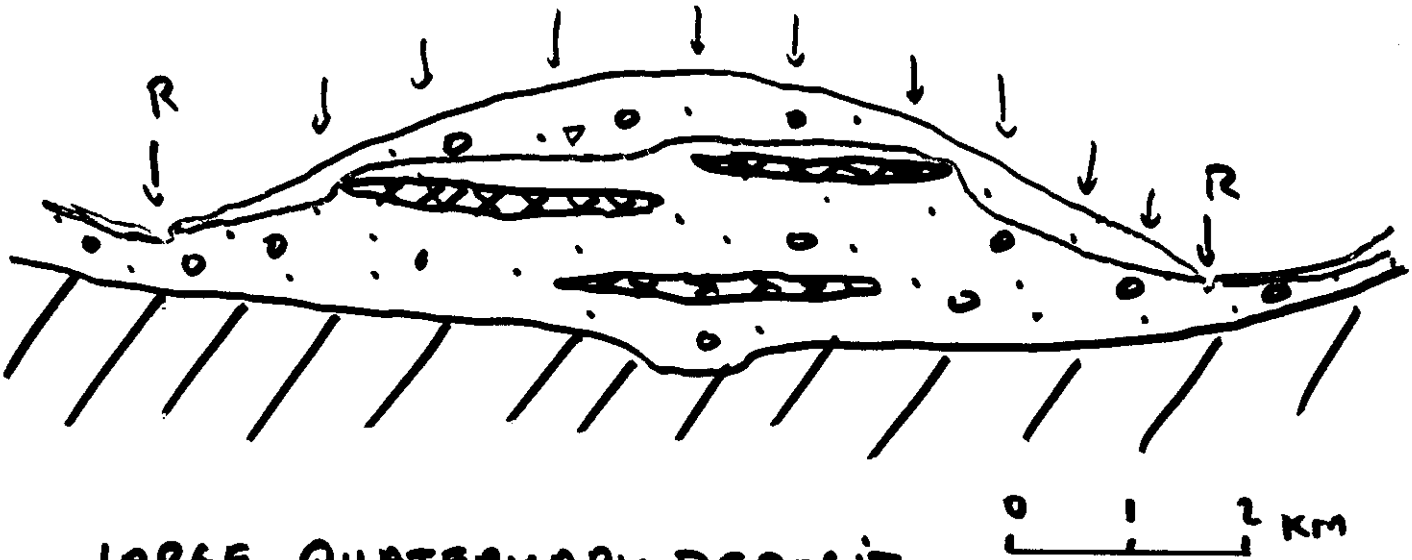


SANDS + GRAVELS (C) OVERLYING LIMESTONES

TYPICAL AQUIFER ENVIRONMENTS.



KARST LIMESTONE



LARGE QUATERNARY DEPOSIT

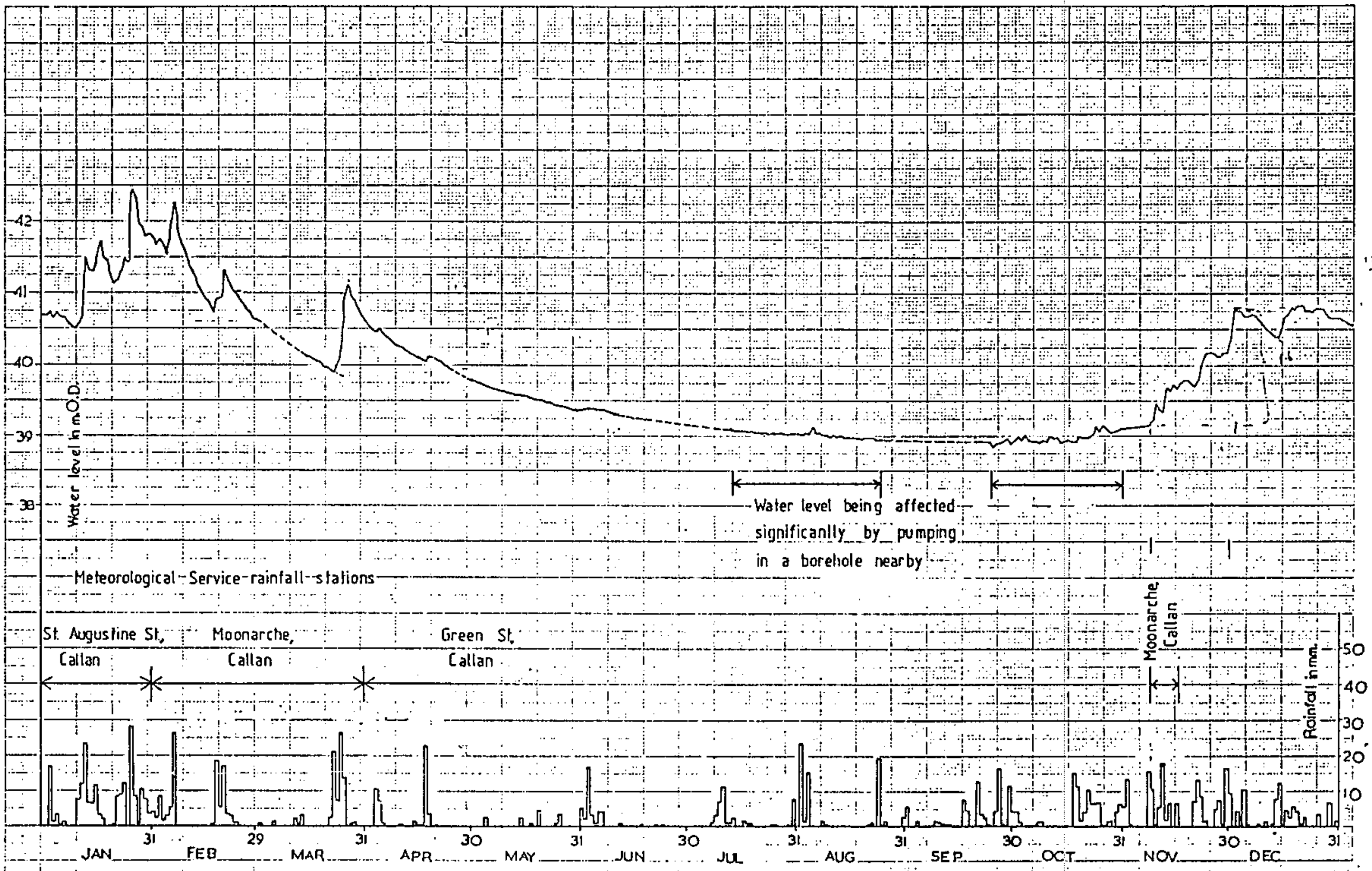


Figure Hydrograph of borehole KNY 27/58 for 1984

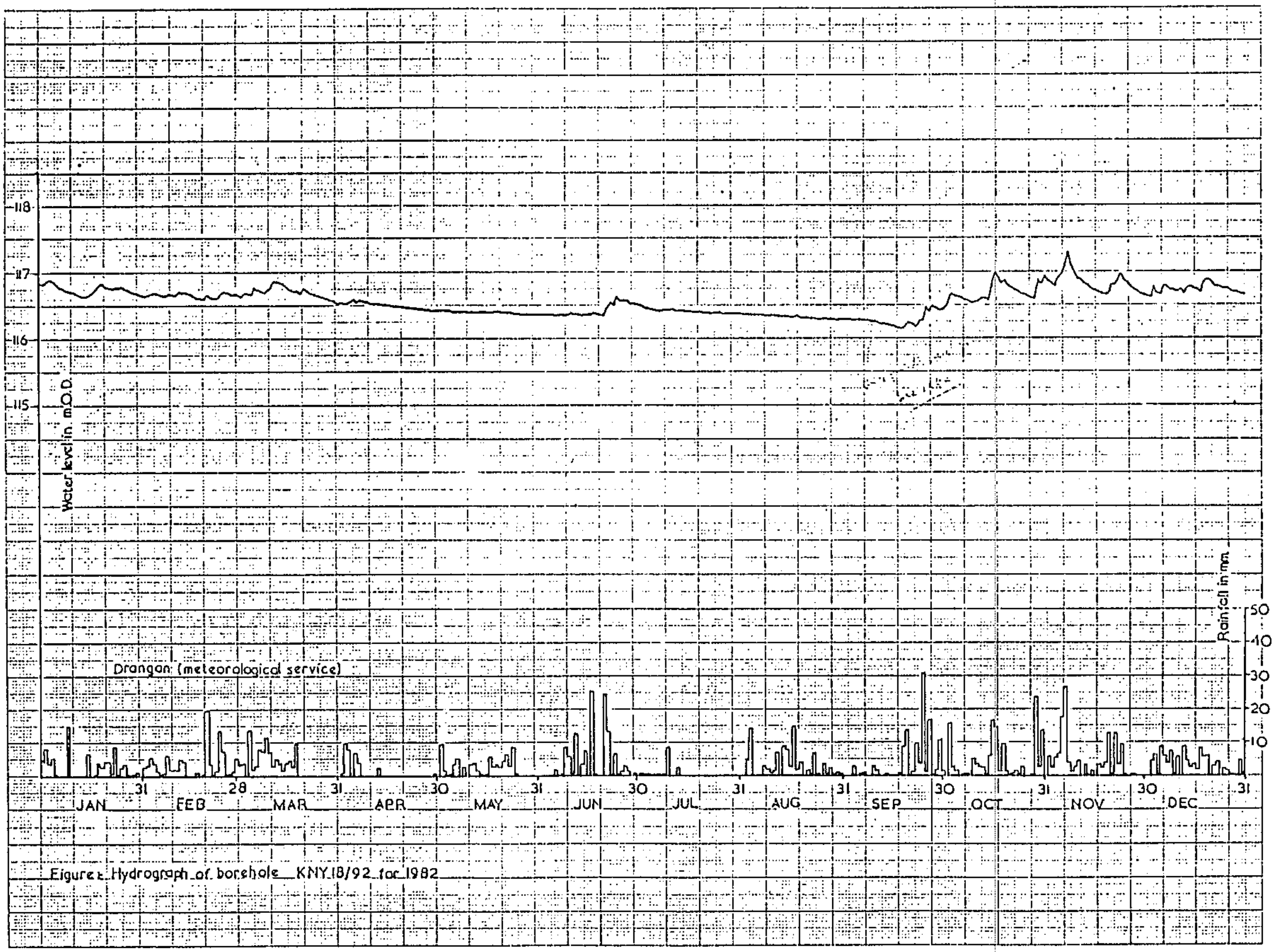


Figure z Hydrograph of borehole KNY.18/92 for 1982

OHS

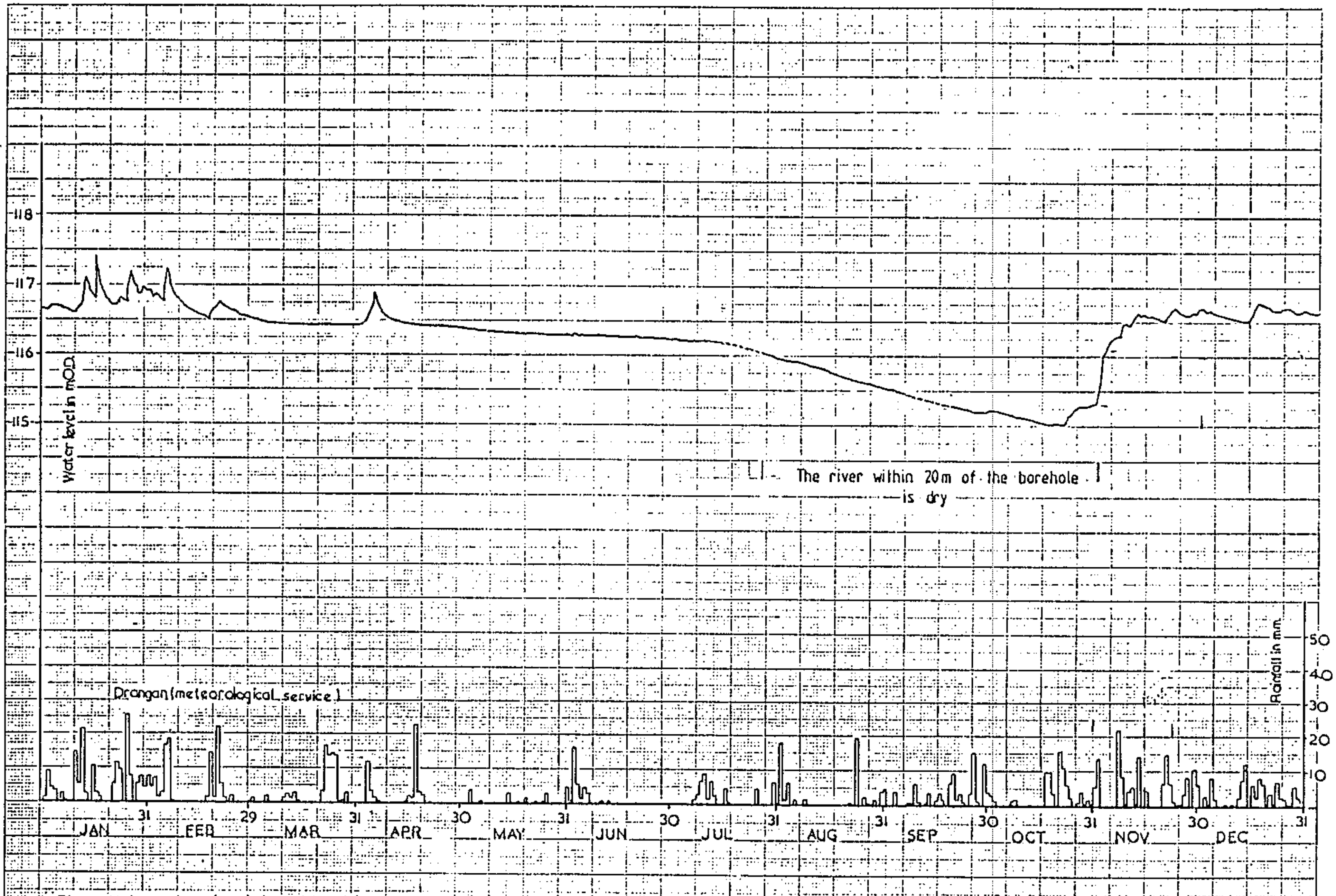
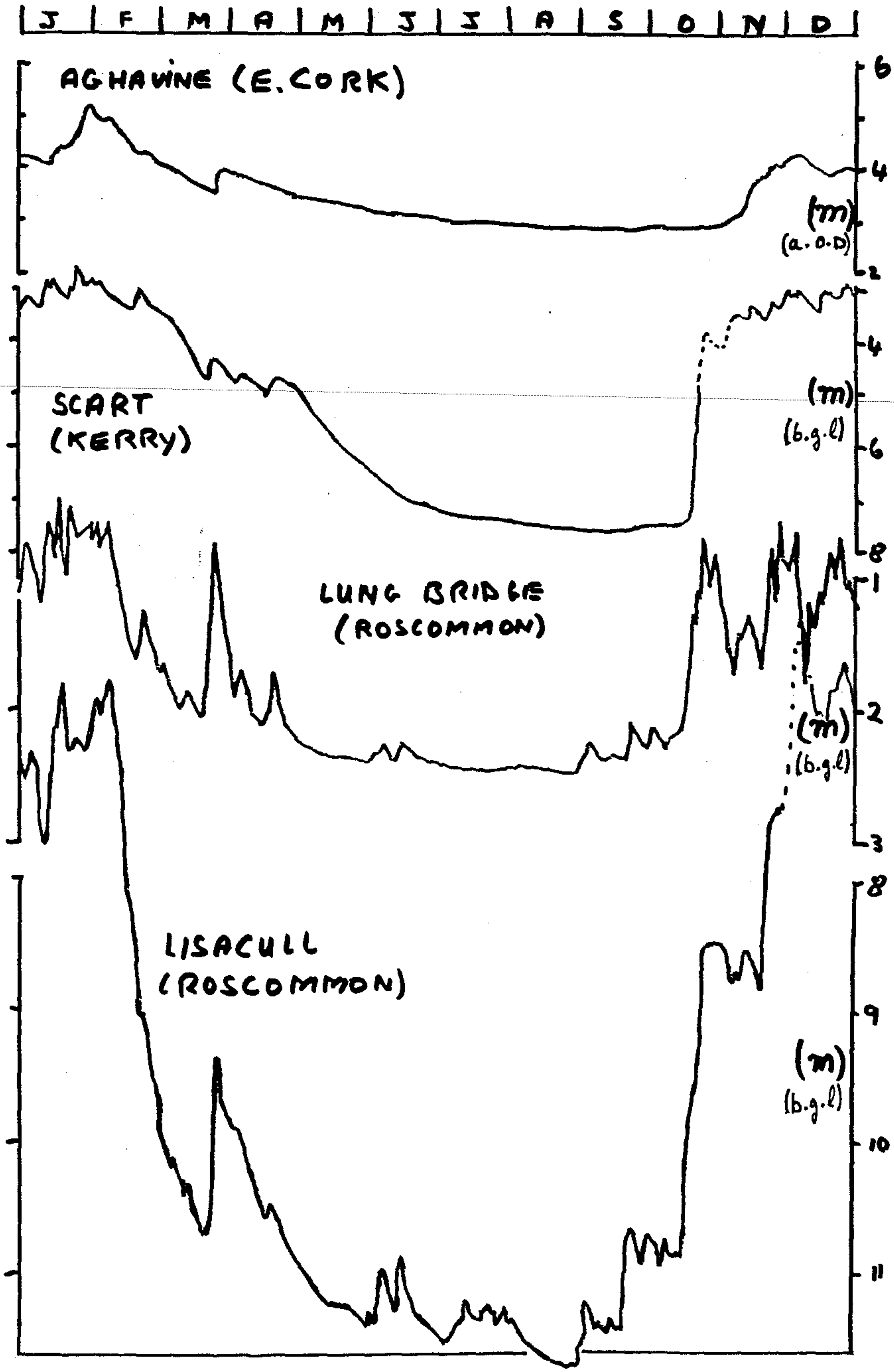


Figure Hydrograph of borehole KNY18/92 for 1984

OH 6



WELL HYDROGRAPHS 1984

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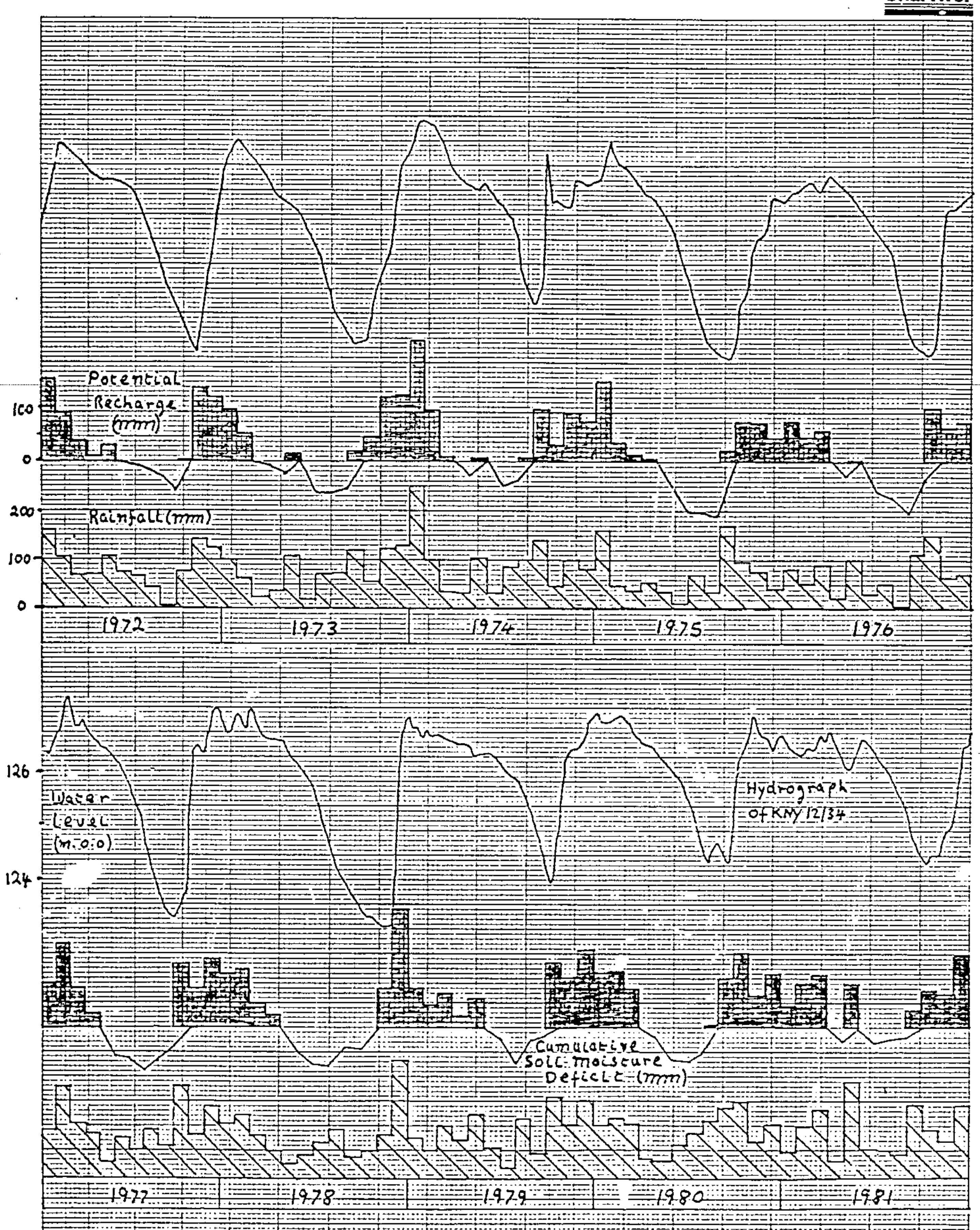
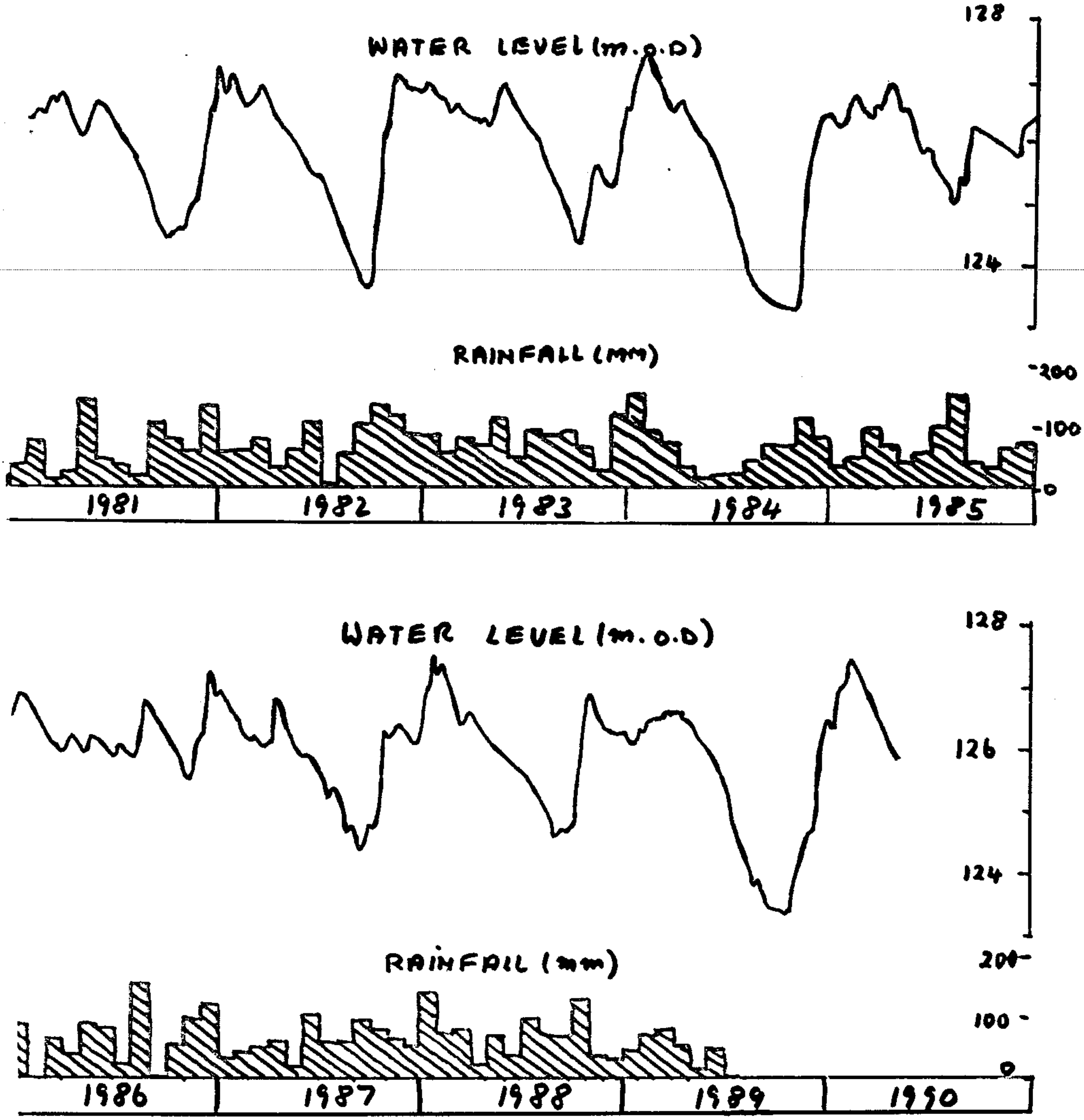


FIGURE I. Hydrograph of well KNY 12/34 and estimates of average monthly rainfall, potential recharge and cumulative soil moisture deficit over the Nore River Basin.



WELL HYDROGRAPH KNY 12/34

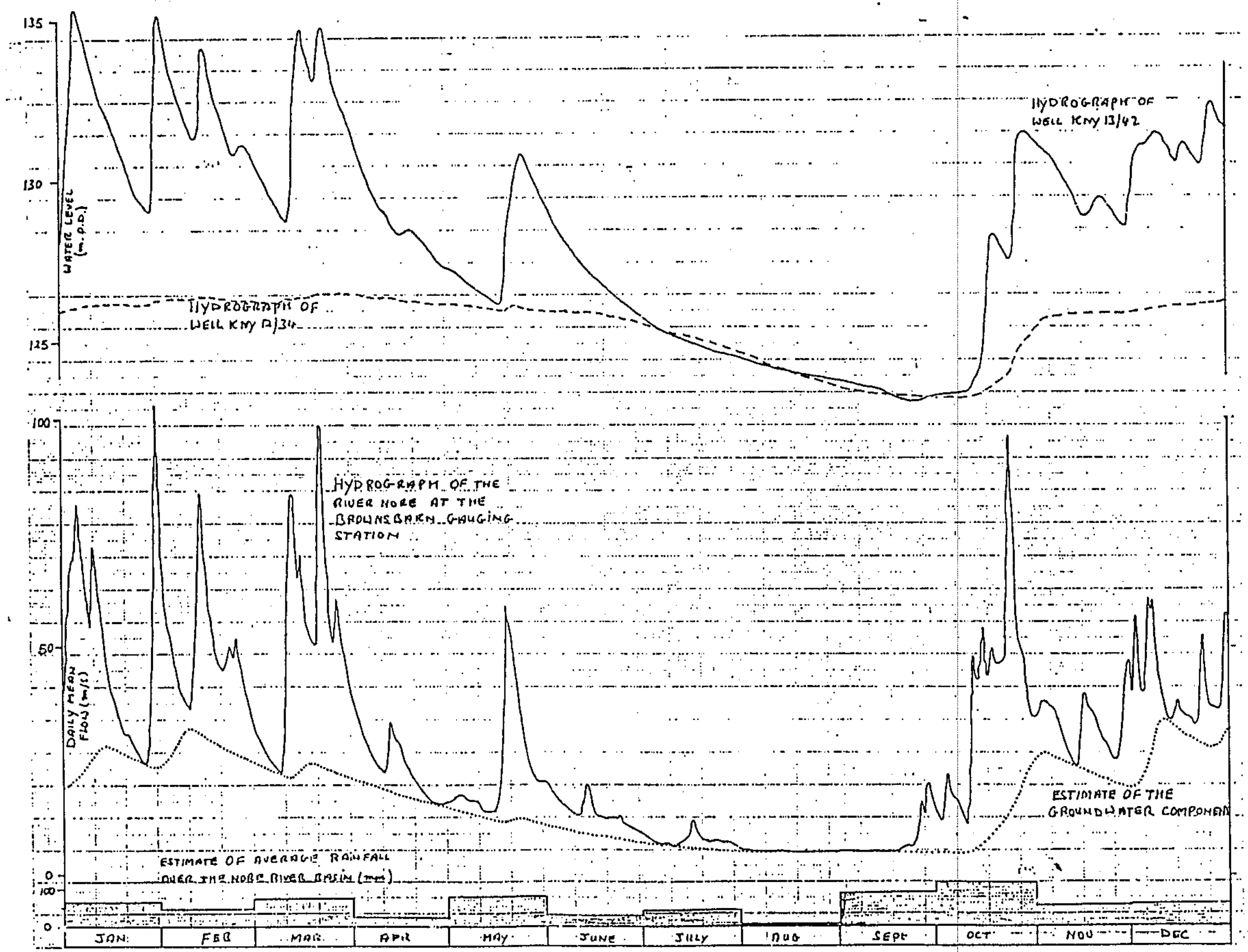


FIGURE V.6 COMPARISON OF THE HYDROGRAPHS OF TWO WELLS AND THE HYDROGRAPH OF THE RIVER NORE IN 1976

CLIMATE CHANGE, METEOROLOGICAL EXTREMES AND GROUNDWATER QUALITY

Richard Thorn, School of Science, Regional Technical College, Sligo.
(With some data supplied by Annette Prendergast, Sligo RTC).

Paper presented to International Association of Hydrogeologists (Irish Group) 10th Annual Groundwater Seminar on 'Climatic Extremes and their Effect on Water Resources', Portlaoise, 1st and 2nd May, 1990.

INTRODUCTION

Changes in groundwater quality span a continuum from rapid fluctuations in karst aquifers responding to recharge events (measured in minutes, hours or days) to much slower changes resulting from major climate shifts (hundreds or thousands of years). Within this span may be found seasonal fluctuations in, for example, nitrate levels in groundwater (cf Croll and Hayes, 1988) and changes over tens of years in, for example, salinity levels, brought about by recent irrigation (cf Barnett, 1989).

For the purposes of this paper two broad categories of groundwater quality change are identified; those deriving from longer term climate shifts (measured in tens, hundreds or thousands of years) and those resulting from shorter term meteorological extremes (measured in months, days or hours) e.g. floods and summer droughts.

CLIMATE CHANGE AND GROUNDWATER QUALITY

Hydrochemistry

Long term climate changes might give rise to the climate of an area becoming:

- cold and dry
- hot and dry
- cold and wet
- hot and wet.

Figure 1 illustrates the relationship between weathering and climate. It is clear that the absence of a solvent i.e. water precludes the possibility of chemical weathering assuming predominance. In the context of this paper this is most relevant where there are also low temperatures and therefore slow reaction rates. Thus, discussion of the effects of climate change on groundwater quality may be confined to the latter three situations noted above.

Because rainwater is not in chemical equilibrium with aquifer materials the most important process governing the chemical characteristics of groundwater is solution of the aquifer materials. The lithologies most affected by solution are carbonates and evaporites but silicates and quartz are also affected. For solution to take place a solvent is needed; in the context of aquifer materials this is groundwater, and, because the solubility of aquifer materials is, at least partially, dependent on temperature then this will also be a controlling factor.

The most widely studied solution reaction, and relevant in Ireland where limestone lithologies are preeminent, is that involving calcium carbonate minerals. The research to date shows a clear relationship between limestone solution rates and climate. This is indicated in Figure 2 which shows the relationship between limestone removal rates and runoff, e.g compare the limestone removal rates for Norway (NOR) (cold and dry) and Madagascar (MAD) (hot and wet) - 130m^3 km^{-2} $annum^{-1}$ for Madagascar and 10m^3 km^{-2} $annum^{-1}$ for Norway. Interestingly, temperature exerts less of a control than might be expected. For example, the removal rates in the Pyrenees (PYR) are similar to some of those noted for Jamaica; the abundance of runoff is obviously a major controlling factor. This phenomenon may be explained by the fact that in order for limestone solution to be most effective the water must contain dissolved carbon dioxide, the solubility of which decreases with increasing temperature. The effect of a rise in temperature is thus partially negated.

In general, were climate changes to result in hotter and wetter conditions then the carbonate concentrations in waters draining limestone areas would rise.

FIGURE 1
Relationship between weathering and climate (temperature and precipitation)

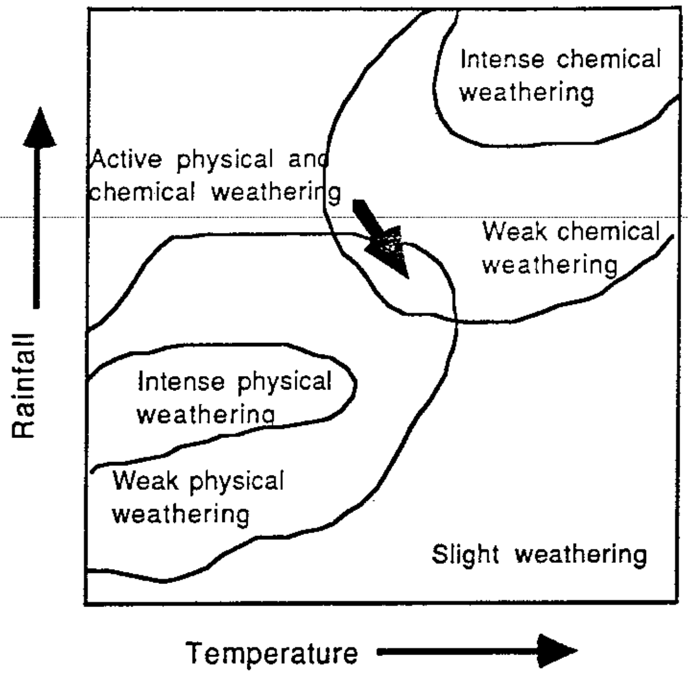
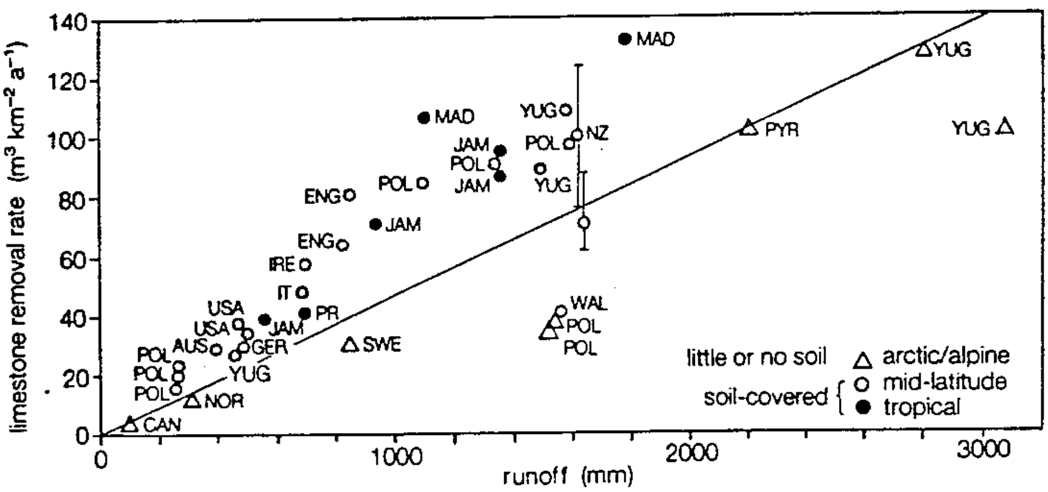


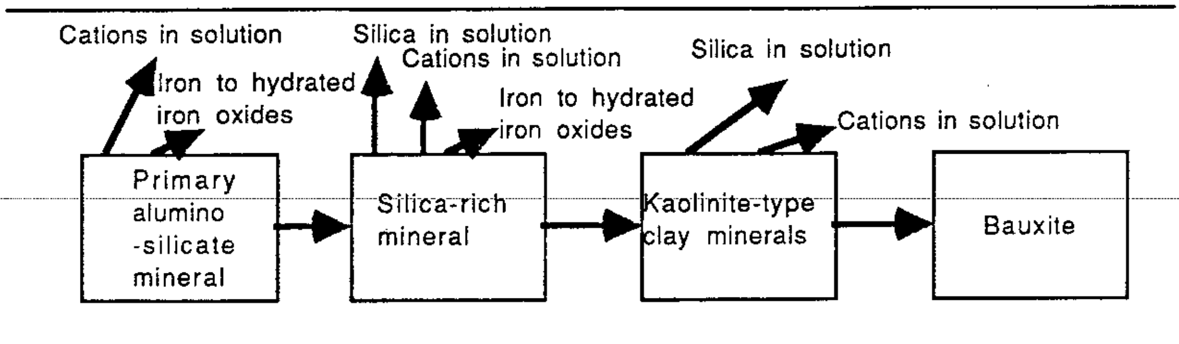
FIGURE 2
Limestone removal rate against runoff



(After Jennings, 1985)

In non-limestone areas the dissolution of alumino-silicate minerals is of most concern. The weathering of rocks rich in silicate minerals, such as granite and basalt occurs most vigorously under hot, wet conditions. Figure 3 shows the course of weathering of an alumino-silicate mineral and the resulting products. The exact 'cocktail' of solution products will depend on the lithology involved e.g. the weathering of basalt would give rise to a solution that includes Si^{4+}, Al^{3+}, Na^{+}, Fe^{2+}, $Mg^{2+}$and Ca^{2+}.

FIGURE 3
The course of weathering of an alumino -silicate mineral



(After Ollier, 1974)

The end product of this weathering sequence, bauxite, forms under hot, seasonally wet conditions. Clearly, the onset of hot, wet conditions would result in an increase in cations in the drainage waters from areas of crystalline rock.

The dissolution of limestone and silicate minerals requires water. In contrast, what are the likely consequences of the onset of hot and dry conditions i.e. perennial drought? Regions with low precipitation (<250mm $annum^{-1}$) can be found in most parts of the world but the areas most widely regarded as deserts lie between latitudes 15° and 50° north and south of the equator. Groundwater in desert areas is usually more saline than in humid areas. There are two main reasons for this. First, the high evaporation rates result in the build up of salts at the surface which can be dissolved by infiltrating water during the the occasional recharge events. Second, the water usually derives from infiltration during wetter and colder 'pluvial' periods, which correspond to glaciations in the temperate regions, and is thus 'fossil' - being, in many cases, thousands of years old. The fact that the waters are usually old, combined with the limited recharge, results in long residence times and ample opportunity for the water to dissolve aquifer materials. Such waters are characterised by high total dissolved solids and chloride levels.

Were climate to become hotter and drier then rises in the salinity of groundwater would be expected as residence times and salt concentrations in soils increased.

Microbiology

The survival and multiplication of microbes in soil and groundwater is dependent on a range of factors including moisture content, moisture holding capacity, temperature, pH, sunlight, organic matter and antagonism from other biological materials in the soil. Of particular interest is the survival of enteric bacteria e.g. *E. coli* and *Steptococcus fecalis.* Enteric bacteria normally survive about two months in soil and perhaps a little longer in groundwater (Broaders, 1989). Increases in the moisture content of soils will tend to increase the survival times but, in contrast, increases in temperature will decrease survival times. Hot, dry conditions will therefore favour more rapid die off of enteric bacteria but it is difficult to predict the likely consequences of the onset of hot, wet conditions.

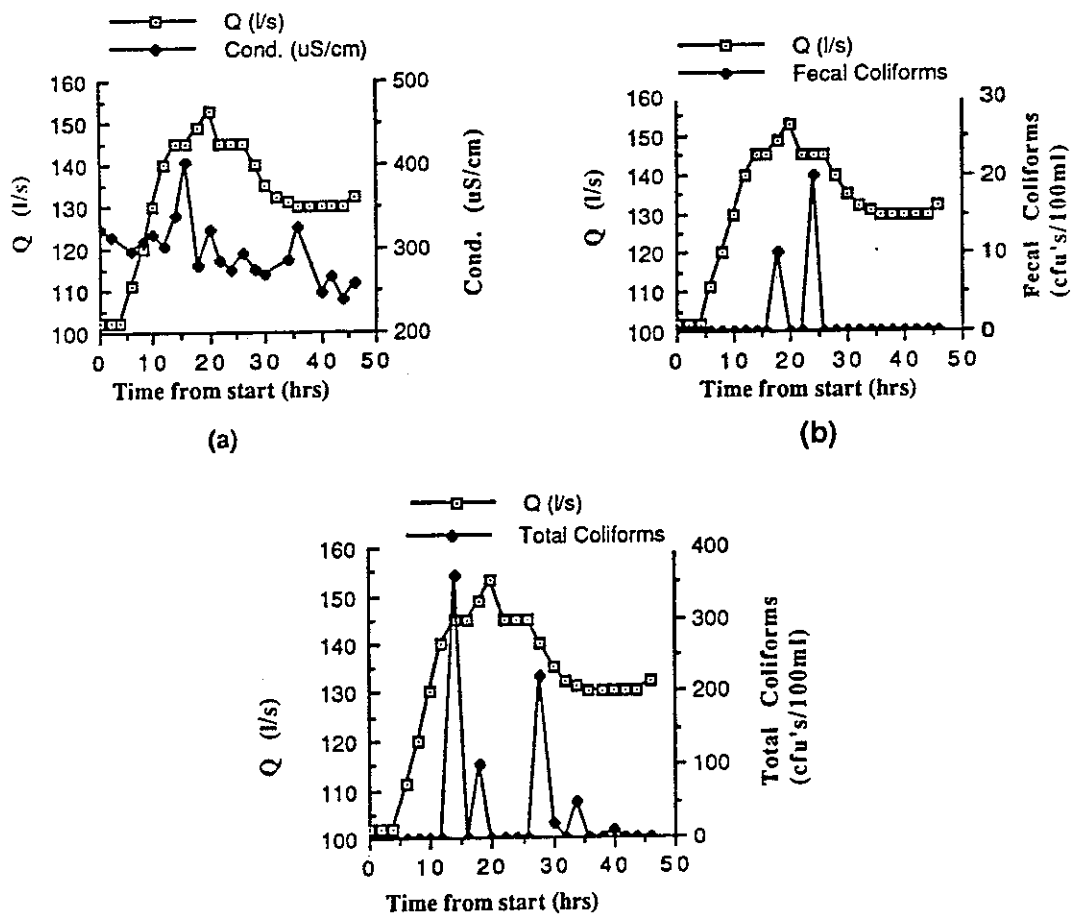
METEOROLOGICAL EXTREMES AND GROUNDWATER QUALITY

Floods

The effects of intense precipitation events on groundwater quality depend on the rapidity of the response of the aquifer to the event. In the case of aquifers with intergranular permeability and with a thick unsaturated zone the effect will be minimal. In contrast, the response in a karstified limestone aquifer with a thin or absent overburden will be rapid and extreme. The response of karst aquifers to such events is complex. It may involve an initial rise in some constituents as water is flushed out of soil and groundwater storage followed by a decrease in concentration as the new recharge waters with a short residence time in the soil and aquifer arrive at the well or spring. These changes are examined in Coxon and Thorn (1989a and b) and Thorn and Coxon (1989a and b).

Until recently few data were available on the changes in the bacterial quality of groundwater during flood pulses in Irish karst aquifers. Where water supplies are unchlorinated the likely changes in bacterial quality during flood pulses are clearly of interest to those managing the supplies. Observations by Drew (1987) drew attention to the relationship between increased precipitation and enhanced bacterial numbers at springs. Figure 4 b and c are 'bacterigraphs' - is this the correct term? for a flood pulse in the Geevagh karst in Co. Sligo. These graphs are the result of recent work which has attempted to elucidate the nature of the mechanisms which result in changes in bacterial numbers at karst springs during flood events. (Figure 4 a shows discharge and conductivity plotted against time and is included to indicate the nature of the hydrochemical changes). The pronounced conductivity peak (4a) prior to the maximum discharge is the so-called 'piston' effect as water that has been in storage is flushed out. The peak in total coliforms (which

FIGURE 4 a, b and c
Graphs of Q, conductivity, fecal and total coliforms against time during a flood event at a karst spring



includes indigenous soil organisms in addition to enteric coliforms) prior to maximum discharge (4c) results, perhaps, from the flushing out of coliforms stored in the soil while the peak after the maximum discharge represents coliforms brought in by recharge water with a short residence time. Figure 4b shows peaks in the fecal coliform concentration during or after the maximum discharge. The absence of fecal coliforms prior to the pek discharge suggests, perhaps, that fecal coliforms have a shorter survival time than indigenous coliforms and that the bacteria in the peaks are derived from recharging waters rather than waters stored in the soil and groundwater. Further work is warranted. Similar trends in bacterial numbers at karst springs during a flood event have been observed by Lavanchy et al (1988).

Summer Drought

Few data are available on groundwater quality changes during summer droughts however the following phenomena have been observed:

- overpumping resulting in increased aeration of the aquifer leading to precipitation of oxidised iron and manganese and a decrease in well yields (E. Daly, Pers. Comm.)
- an increase in bacterial numbers in some high yielding wells (observed by C. Coxon and the author) - perhaps due to recharge from nearby septic tanks?

CONCLUSIONS

As far as climate change is concerned the following conclusions may be drawn:

Climate becoming **hotter and wetter** -	Increase in hardness and and cations in groundwater
Climate becoming **hotter and drier** -	Rises in the salinity of groundwater. More rapid die off of enteric bacteria.

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FLOOD WARNING SYSTEM FOR KILKENNY CITY

By H. D. Shine, Office of Public Works.

Immediately following the serious flooding on Christmas Eve 1968 I was asked to examine the possibility of providing some sort of advance warning system which would at least give the various groups involved some time to prepare.

I began the study by checking all the records of gauges upstream of, and including, the gauge at Kilkenny. There were seven Automatic Recording gauges, all of which were constructed between 1953 and 1955. These are shown on the sketch map and there was an average of fifteen years of record from each gauge available for examination.

It became clear very quickly that flood peaks occurred in Kilkenny long before the peaks occurred at any of the other gauges upstream with the exception of the gauge at the River Dinin, indicating that high flow from that river was the principal cause of high flow in the River Nore through Kilkenny.

The River Dinin has a catchment area of 298 km^2, compared to the total catchment area to Kilkenny of 1605 km^2 or roughly one fifth of the total contributing area. The general slope of the Dinin is steep and the time of concentration is comparatively short which creates high flood peaks, or short duration in association with high intensity rainfall.

With this background information, I began a detailed study of the charts for the gauges at Dinin Bridge and Kilkenny and listed every flood which has occurred since the beginning of the record.

I listed the information under the following headings - Date, Pre Flood Level, Time, Peak Level and Time of Peak Level.

The next step was to list the "Actual Rise in Level" i.e. the difference between Peak Level and Pre-Flood Level during each flood at the two gauge sites and finally to compare the actual rises in level with each other.

I plotted each "Rise in Actual Level" at Dinin Bridge against the corresponding "Rise in Actual Level" at Kilkenny and this plot demonstrated two significant facts:-

(1) A definite relationship between flood peaks, many of which had a straight line relationship and the remainder varying between 20 cm below the average too 20 cm above.

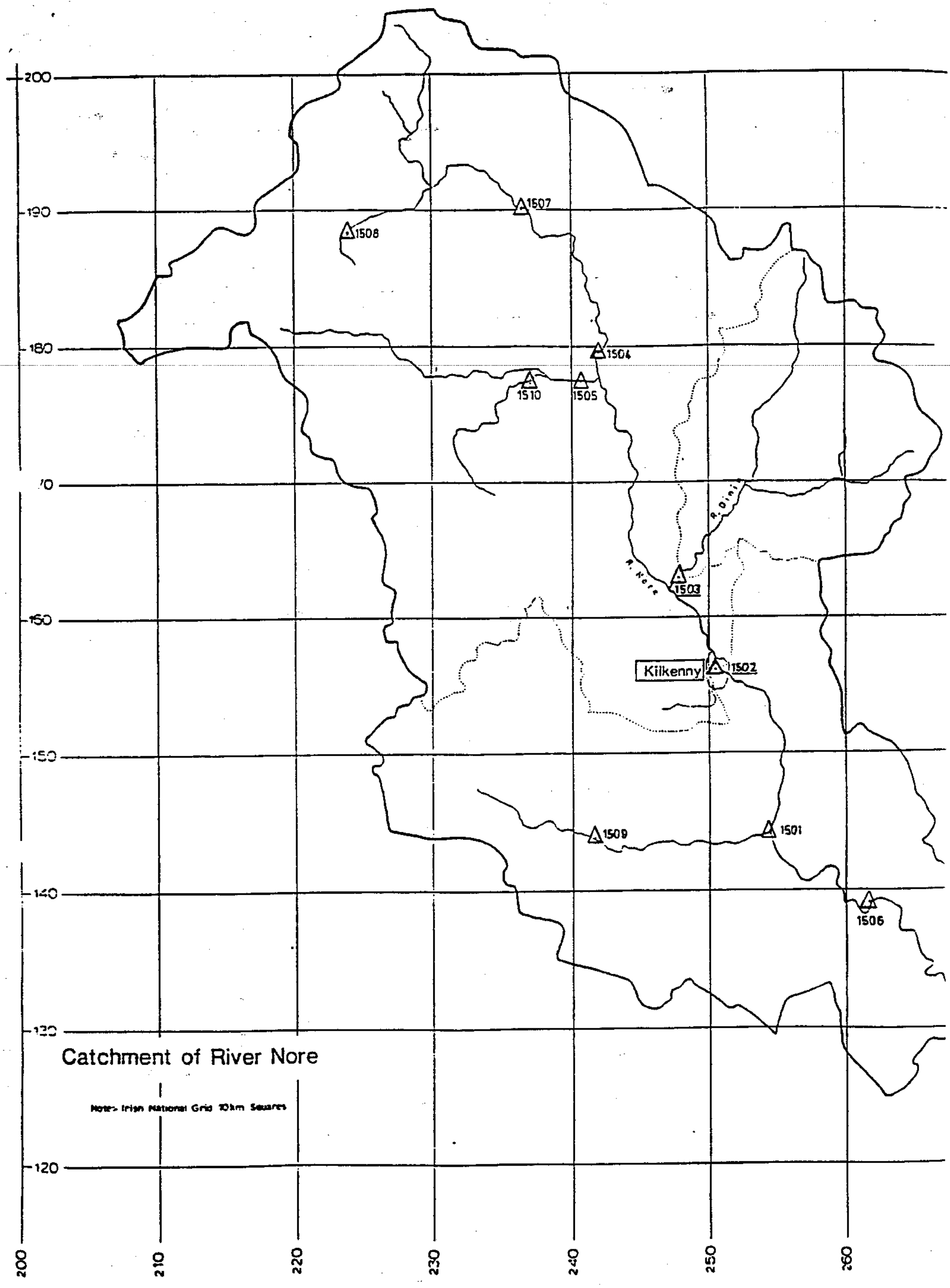
(2) There was a definite level at Dinin Bridge below which, no flood would occur in Kilkenny. This meant that only floods at Dinin Bridge which exceeded this cut off point should cause any concern.

The operation of the warning system depends on visual observation of the behaviour of the flood at Dinin Bridge. After heavy rain it is necessary to inspect the gauge at Kilkenny and note the pre flood level; then the Dinin gauge is inspected. First the pre-flood level is noted and the peak level when it is reached. When the peak level is known the Rise in Level is calculated and, from the plot, the expected rise in level in Kilkenny can be predicted with a reasonable degree of accuracy.

The ground levels at various points in the city which are subject to flooding are known and, therefore, flood warnings can be issued to those concerned, giving usually about four hours notice.

The major difficulty with the system lies in the fact that at present it is necessary for some one from OPW staff to be available in Kilkenny and this is not always certain due to the widespread area covered from this base. It might be preferable to have perhaps some organisation such as the Fire Service who maintain a 24 hour duty roster actively involved during the initial stages. This could be completed with an automatic alarm system at Dinin Bridge which would be activated as soon as the cut off level was exceeded.

Basically, what happens when flooding is expected in the Kilkenny region, the various organisations, such as Corporation, County Coucil, Fire Service, Gardai, each have a recognised role to play which has been agreed at joint meetings and until such time as remedial protection work can be carried out the warning system will provide some measure of assistance to those affected by this periodic flooding.



Catchment of River Nore

Note: Irish National Grid 10km Squares

THE STRUCTURE of FLOOD FLOW in RIVERS WITH FLOODPLAINS

Ger Kiely and E.J.McKeogh,
Civil Engineering Dept.,
University College Cork.

1. INTRODUCTION

1.1 Background

The climatic extremes of storms with higher rainfall intensities, causes increases in runoff, resulting in higher river flood flows. This has very serious implications for river engineers who are charged with river management programs that are designed to protect urban areas from flooding. It also has implications for other river activities, including water supply, fish production, liquid effluent disposal, and energy production.
Recent media reports on river flooding not only in Ireland but also in such places as Bangladesh and the Sudan, have concentrated on the complex causal nature of such floods, including land use changes, deforestation, sediment movement, urbanisation and changes in rainfall patterns and intensities. At the level of flood analysis of stage-discharge estimation and velocity distribution, hydraulicians have been unable to provide convincing analyses for the case of river flooding, when the floodplains become inundated. The reason for this is the breakdown of conventional formulae, such as Manning's equation, when a river bank is overtopped and floodplain flow occurs. The method of sub-dividing the compound channel flow into main channel and floodplain sections, and summing the discharges in each sub-section, simply does not work. Similarly, considering the compound channel as one section, and using a single weighted resistance coefficient (i.e.Manning's n) does not work either. This is because large turbulent interactions between the faster main channel flow and the slower floodplain flow, generate very significant energy losses, not accountable in the above mentioned simple methods. In overbank flood flow, momentum is transfered from the main channel to the floodplain causing the main channel flow to be retarded and the floodplain flow to be accelerated.

1.2 Flood Alleviation

In the past, river flood alleviation measures included, deepening and widening the main river channel, with the rare occurence of flood control by reservoirs (i.e. Inniscarra Dam in Cork). Floods were then contained within the single main river channel, and their analysis and stage-discharge estimation, were predictable by well proven hydraulic theory.

In this era of environmental awareness, such measures may be considered undesirable as they can interfere with the biology of river wildlife, disrupting the plants, invertebrates, amphibians, reptiles, fish, mammals and birds. A less disruptive option is the compound channel (Kiely 1985). This involves, earthworks which do not encroach on the main channel. The floodplain at the side of the main channel is lowered, to some low water level, for a width equal to about the main channel width, thereby creating a two-stage or compound channel as shown in figure 1. However the flow analysis of this complex section is less well understood. It is not yet possible to predict accurately, the stage-discharge relationship or the velocity distribution for the two stage channel. Experimental research by Kiely and

Mckeogh (1989), at University College Cork have addressed the problem of overbank flow in straight and meandering channels.

2. EXPERIMENTAL INVESTIGATIONS

2.1 Experimental Arrangement

The experimental work was carried out in a 14.4m long by 1.2m wide recirculating flume. The flume height was 0.5m with a discharge capacity of 50L/sec. A test section, 2.4m long was located 7.2m from the inlet.A glass floor in the test section allowed access for Laser Doppler Anemometry (LDA) measurement system. Within the main flume, a series of compound channel configurations were constructed, including:

1. A straight symmetric compound channel with a 0.2m wide by 0.05m deep main channel, flanked on both sides by 0.5m wide floodplains as shown in figure 2.
2. A multiple meander compound channel with dimensions shown in figure 3.

For the straight channel, one cross section was chosen and velocity and turbulence measurements were taken for five overbank depths, and three different floodplain roughnesses. For the meandering configurations, seven sections as shown in figure 3, were investigated for three overbank depths. Approximately two hundred data points per section were recorded.

3. RESULTS

3.1 Stage-Discharge

The stage-discharge curves for the straight compound channel with smooth and rough floodplains are shown in figure 4. At low overbank depths, it is seen that the discharge is less than that at bank-full. This is due to the transfer of momentum from the main channel to the floodplains, resulting in the main channel loosing some of its enegy and discharge capacity. At low overbank depths, the floodplains have a very low discharge capacity due to the higher resistance to flow. Other experiments have quantified that Manning's n is depth dependant, with higher values at low depths.

3.2 Depth Averaged Velocities in the Straight Compound Channel

Figure 5. shows the depth averaged velocities for the straight compound channel with smooth floodplains. The five lines, a to e, correspond to the results for five experiments with flow depths ranging from 50mm overbank to 10mms overbank. The left floodplain is shown along with half of the main channel, because of symmetry. Examining line c, corresponding to an overbank depth of 30mms, it is seen that most of the floodplian has an almost constant velocity. The area between the main channel and floodplain is an active zone called the interface zone. As the interface is approached from the floodplain, it is seen that the floodplain velocity increases. The maximum velocity occurs at the centre of the main channel. As the interface zone is approached from the main channel, the velocity decreases, and close to the interface, the main channel velocity is actually lower than the adjacent floodplain velocity. The width of the interface zone, on each side of the interface is appproximately equal to the depth of the main channel. At low overbank depths, there is a steep gradient of velocity across the interface, leading to high shear stresses. This has scour implications for embankment design and bridge abutments placed close to the interface.

3.3 Depth Averaged Velocities in the Meandering Compound Channel

Figure 6, shows the lateral distribution of depth averaged velocity across section 1, of the multiple meander configuration, of figure 3. This is for one floodplain depth of 30mms, with smooth floodplains. Section 1, is at the apex of a bend. It is seen that the maximum velocity across the the full section is not in the main channel as might be expected, but at the outer regions of the floodplain. In the main channel, the maximum velocity is at the inner bend. There is also a second peak in the floodplain close to the inner bend. This suggests a fast fluid filament running down the centre of the overall compound channel. In the wider floodplain, about midway between the inner bend and the outer floodplain, there is a sag value in the velocity. It must be noted that these experiments were performed with a horizontal bed in both the main channel and floodplain.

3.4 Resultant Velocity Vectors

Figure 7, shows a plot of the resultant velocity vector, 20mm above the floodplain bed, for a flow depth of 30mm above the floodplain. It is seen that the direction of the floodplain flow is essentially longitudinal. The direction of flow over the main channel tends to be longitudinal at the bend apices. Similarly between the bends the direction (over the main channel), tends to be parallel with the walls of the main channel underneath. The velocity magnitudes show floodplain peaks, at the outer floodplain and a second peak close to the inner bends. The sag in the velocity distribution is visible at all seven sections. The peak main channel velocity occurs at the inner bend, suggesting the existance of free vortex flow behaviour.

3.5 Secondary Currents

Figure 8, shows a plot of the secondary currents at Section 1, for the meandering configuration. The plot is confined to the width of the main channel, but includes the above bank main channel flow. It is seen that there is a distinct anticlockwise secondary cell. It is known for inbank flow that a secondary cell exists, but it has a clockwise motion. So in the process of going fron inbank to overbank flow, the secondary cell direction goes from being, clockwise for inbank flow, to no secondary cells at low overbank depths, to anticlockwise at deeper overbank depths.

4. MATHEMATICAL MODELS

Conventional mathematical models used in determining stage-discharge, in compound channel use area averaged methods. For instance, the velocity determined in the main channel will be a single value, normally obtained fron inputing a single resistance coefficient. Similarly the floodplain velocity determined will be a single value. As such these methods do not identify the hyperactivity in velocity and turbulence that is known to exist at the interfaces of main channel and floodplain. These area averaged methods are in widespread use, and for the river engineer, they are considered a very useful tool, but cannot be used in overbank flood situations without calibration with a known flood discharge and corresponding flood levels. However the latter set of information may not be known as we are now experiencing higher floods, for which there are no recorded points on the stage-discharge curves. This poses problems for the engineer involved in flood alleviation. This underlines the need for not only better understanding of the mechanisms of flood flow but also the urgency for which more sophisticated mathematical models are needed.

The next improvement above area averaging, is to produce a 1-D model. This would produce a continuous velocity distribution of depth averaged velocity across the compound section. As such it would then incorporate the changes in distribution in the interface region. Continuing work, in solving the dynamic equation, suggests that within a 1-D model it is possible to incorporate the changes in the interface area. The equation is:

$$gS_o - \frac{fU^2}{8h} + \frac{\delta}{\delta y}\left(\nu_t \frac{\delta U}{\delta y}\right) = 0$$

g =gravity acceleration, S_o =longitudinal water slope
f =friction factor, h =depth of water, ν_t =eddy viscosity
y =lateral dimension, U =depth averaged longitudinal velocity

This is the 1-D form of the depth averaged version of the equation and is solved by non-dimensioning, separately in the floodplain and in the main channel. Figure 9, shows a plot of the predicted velocity distribution versus the experimental results. The trends of the predicted curve are correct but the absolute magnitudes need to be fine tuned. Futher development of this model is ongoing, with particular reference to understanding the edddy viscosity contribution.

5. CONCLUSIONS

1. The velocity distribution in straight compound channel flow is complex and is inadequately represented by current models.

2. At low overbank flow depths, the compound channel discharge is lower that that for bank-full flow.

3. At the interface zone there are steep velocity gradients, across which momentum is transfered from the faster main channel flow to the slower floodplain flow.

4. High shear stresses are experienced at the interface area with implications for design of flood embankments and bridge abutments.

5. The flow behaviour in meandering compound channels is extremely complex, with the occurence of significant secondary currents not only at bends but also on the straight tangent lengths between bends.

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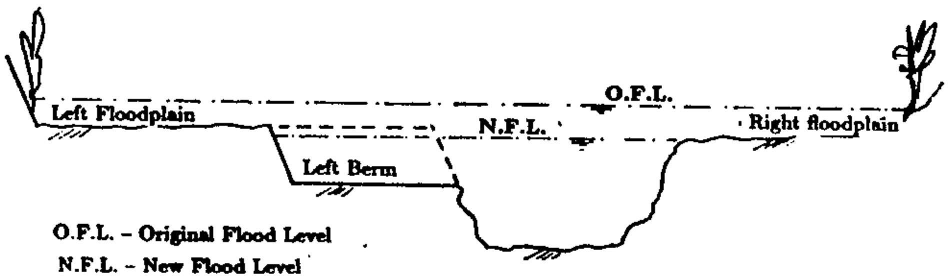

FIG. 1. **COMPOUND or TWO-STAGE CHANNEL**

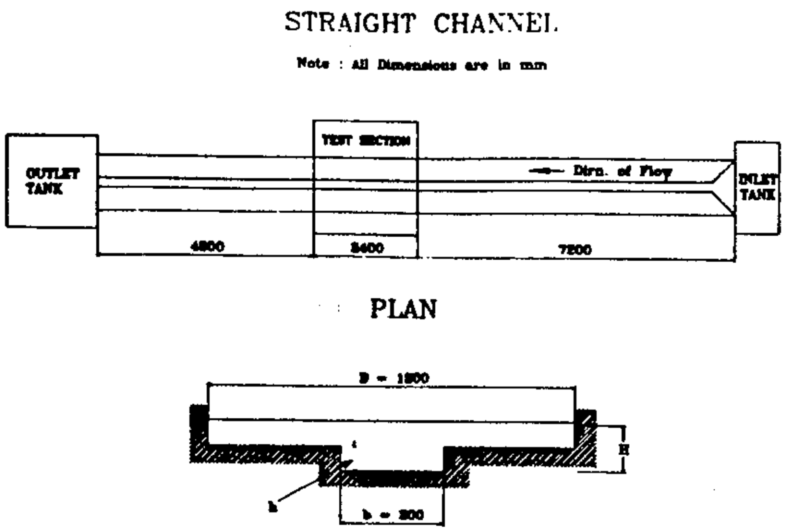

FIG. 2. CROSS–SECTION

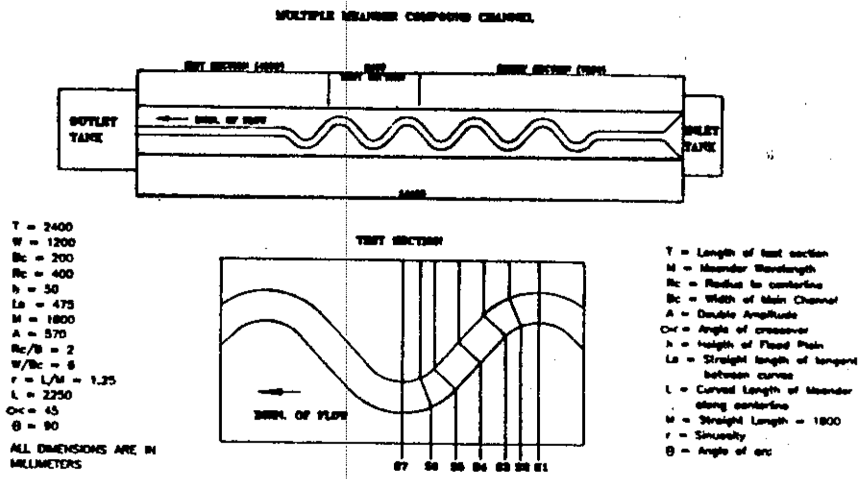

FIG. 3.

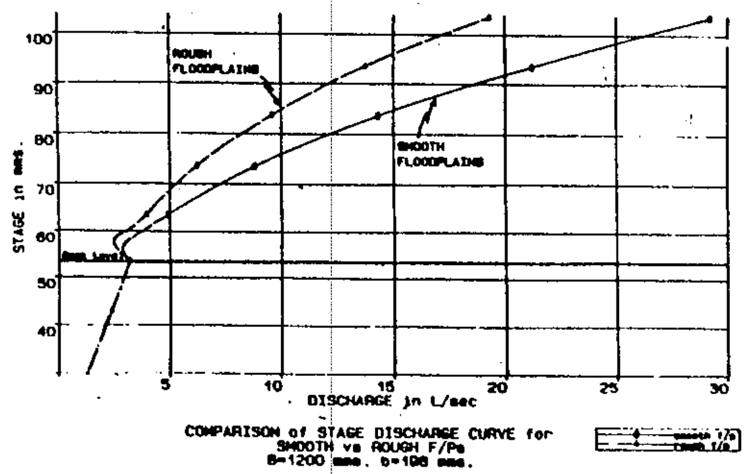

FIG. 4.

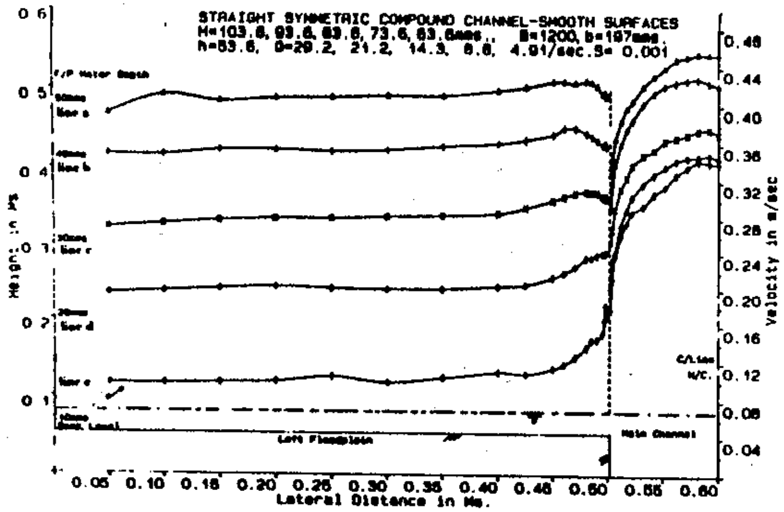

FIG. 5. LATERAL DISTRIBUTION of DEPTH AVERAGED VELOCITY

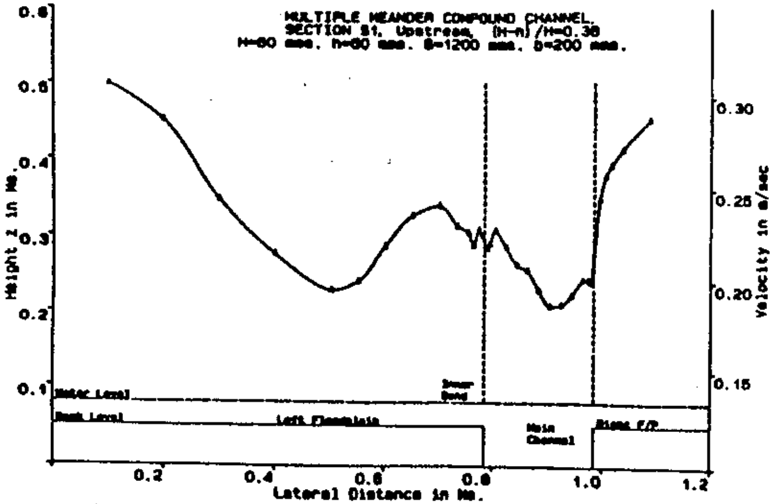

FIG. 6. LATERAL DISTRIBUTION of DEPTH AVERAGED LONGITUDINAL VELOCITY.

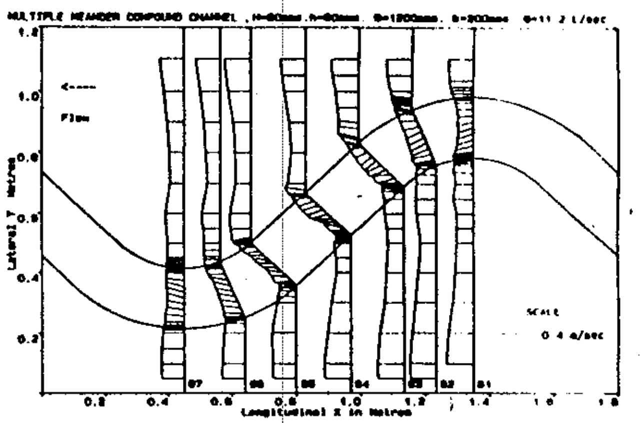

FIG. 7. RESULTANT VELOCITY VECTOR PLOT at 30 mm ABOVE THE F/P BED

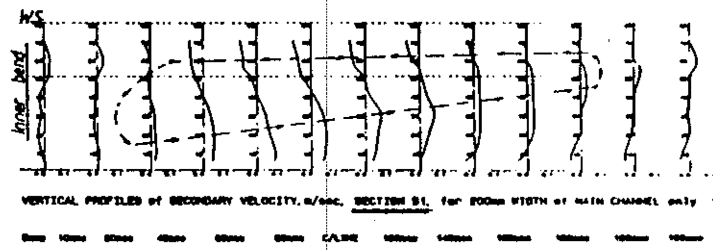

FIG. 8. VERTICAL PROFILES of SECONDARY VELOCITY, m/sec, SECTION S1, for 200mm WIDTH of MAIN CHANNEL only

MULTIPLE MEANDERING COMPOUND CHANNEL, H=80mm, h=80 mm, B=1200 mm b=200 mm

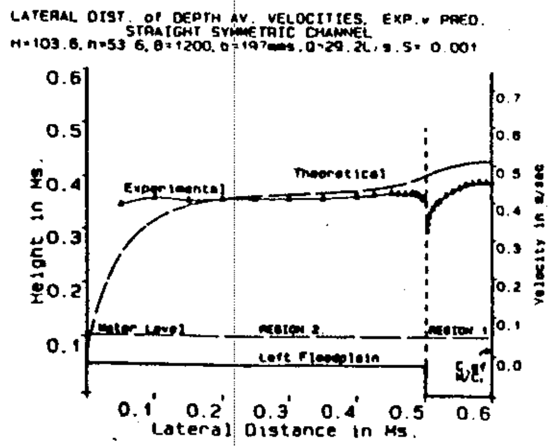

FIG. 9. Physical Regimes used in Theoretical Model: Matc. conds at interface. U, dU/dy cont. Bdy cond at side wall, U=0. Bottom friction f. constant, f from mean exp. data. Variable Eddy Viscosity.

International Association of Hydrogeologists (Irish Group)
10th Annual Groundwater Seminar, Port Laoise. 1st. & 2nd May 1990

COPING WITH LIMITED WATER RESOURCES WHAT WE CAN LEARN FROM ARID AREAS

The aim of this paper is to answer the question:-

"Does the response of society and hydrogeology in other areas to drought and climatic change have any relevance to Ireland and the climatic changes that may be taking place here?"

The short answer is an emphatic "yes". The relevance is at two levels:-

1.Perceptions about water availability/drought.

2.Practicalities.

1. Perceptions

Perceptions about water availability are fundamental. Everyone, in an ideal world hopes for, or assumes, an infinite availability of water. When this does not occur, people often use the term drought. However it means different things to different people. It is a relative term.

The term climatic change is also a relative term. An example of this is that there are some mid latitude desert areas that in winter experience in 24 hours a greater range of temperature and humidity than Ireland experiences in a century (-5^{o}C to +45^{o}C and 100% relative humidity to 5% relative humidity). But this range is not unusual in these areas. Climatic change is relative to the norm, and as meteorologists / climatologists will tell us, defining the norm is difficult.

The word drought means "a dryness, a want of water or rain, a condition of the atmosphere favourable to drying".

This is a loose and perhaps limited dictionary definition. I prefer drought to be used with a clearer, more broad meaning as follows: "Drought is a state, at a particular point or area on the earths surface, at a moment of time,.where the available, usable water is not adequate to meet the ideal requirements". By this definition all parts of the world

David M. Ball (Environmental Resources Analysis Ltd., 5 South Leinster Street, Dublin 2)

at sometime suffer drought. Cities suffer from drought, countries, like Ireland, suffer droughts, as do, of course, areas like the Sahel, Middle East and the centres of large continents.

I address the word "drought" to illustrate the difference in perceptions between Ireland and elsewhere. An Irish farmer or hydrogeologist would regard the Sahel as in a permanent state of drought. Water resources are very scarce or limited. Yet to the people who live in this area, droughts in their perception are rare. Dryness is seasonal and there are times when water is so plentiful they cannot use it. In fact an excess or prolonged period of abundant water can often be a catastrophy.

Drought is therefore defined by society's or an individual's expectations and requirements, not just by amounts of rainfall or water availability. If you expect to grow rhubarb, sugar beet or paddi rice do not go to the southern fringes of the Sahara, but if you want a crop of millet or sorghum it may be just the place.

In the broad definition I have used the terms "available, usable water". This is an important qualification where perceptions differ.

In Ireland we perceive "good water" or available, usable water as being low in dissolved minerals, uncontaminated by radioactivity, heavy metals, artificial organic chemicals and bacteria and viruses. In Ireland we judge water by certain standards and we would not recommend the use of a contaminated water if it was not feasible to treat it and bring it up to certain quality standards. Even though Ireland is behind say the USA or parts of Europe in terms of assessing water quality and imposing standards, it is never the less true that we perceive quality as a priority, and as more of a restraint than quantity.

In areas of perennial and seasonal aridity the perception is the opposite. Quantity is the main pre-occupation, and quality is secondary. Water in the Sahel is a liquid or vapour. If it is available then it can be used, conserved, and if necessary radically treated. Saline brines in desert or coastal salt flats are regarded as available usable water. They are part of the total water resources. Similarly humidity in the air is harvested as dew and used for agriculture in Israel.

The possibility of climatic change affecting Ireland and causing a relative shortage of water raises the question of whether our perception of "good water" is correct. Maybe our standards for usable water are too high. If we maintain an expectation of high standards

David M. Ball (Environmental Resources Analysis Ltd., 5 South Leinster Street, Dublin 2)

particularly on levels of say acceptable dissolved minerals or traces of organic chemicals, we may in effect compound the impact of aridity from climatic change. We may suffer man induced climatic droughts by altering the atmosphere, and a man induced water quality "drought" by either contaminating our water resources, or by society expecting ever higher or tighter application of water quality standards. The effects of industry and agriculture are likely to deteriorate the quality of groundwater in the future. We may decide (if we maintain or harden) our water quality criteria that groundwater or surface water in certain areas is unusable. Hence we remove its availability.

Another aspect of the definition of drought is insufficient water to meet man's ideal requirements at a particular place. This part of the definition draws in two other factors; politics and development. They are usually linked together but in extreme cases can be split. Politics reflect and can control expectations, and can involve the mass movement of people. Wars can cause drought by destroying the fabric of society and the infrastructure used to manage or conserve water. Ethiopia is an example. Political leaders can move people into alien or virgin areas to either ease overcrowding or remove a large adversary group. This can result in either a destruction or a distortion of a natural balance and a drought can result. When this happens astute politicians then blame it on climatic change and call for help from the world community, eg. Transmigration projects in Summatra and Sulawesi, and political "droughts" in North Nigeria/Ghana.

Development programmes whether inspired by politics or economics often create a "drought" because they are often inappropriate in their design and application. In the search for a scape goat their failure is again usually blamed on climatic change. Examples of this are so numerous it is almost possible to believe it happens to every development project in sub Saharan Africa.

Politics and large scale development projects may seem a far cry from Ireland at present. But with centralisation of decision making in Brussels it is not inconceivable that in the future (perhaps in response to climatic change) there are European sponsored developments that encourage irrigation and involve groundwater. They may be ill-conceived; and if our perceptions do not change and we don't consider the long term implications, a "drought" may occur because groundwater is overexploited and yields, or quality deteriorates.

2. Practicalities

Assuming that there is a future negative change in the water resources in Ireland, the first obvious practicality would be to change the perception about drought and total water resources. This would be achieved by a large shift in the perspective of education programmes whether it is in the schools, media or professional conferences like this. It is a shift to total water resources and all the connections between them, humans and the world environment. The connections are extraordinarily complex. The public and leaders in the developed "high Tech." world are only now beginning to get a hint of this complexity. However we still think about water, then mans requirements (man the superior being who by intellect and power is able to control) and then the environment. In many ways the simple, "under- developed" nomadic or "subsistance farming" communities have a far more realistic understanding of this complexity than we do. This greater understanding forces or should force outside technocrats to be more realistic in their application of, for example, hydrogeology.

Most projects overseas involve a critical assessment of the total available water resources. Water is usually a major constraint to all forms of economic or social development, therefore initial surveys are wide ranging and all aspects of the hydrogeological cycle are quantified as accurately as possible.

The consideration of groundwater exploitation always involves a regional perspective. There is a much greater integration of rainfall, runoff, evaporation, soils, natural vegetation, landuse socio-economics and groundwater resources. There is a focus on crop water requirements.

Groundwater modelling achieves an eminence that is not necessary now in Ireland. The initial surveys and models then provide the basis for development proposals that by necessity focus on resource management and conservation. Different options are considered on a regional scale and then a local scale.

Groundwater development projects are planned and executed with a combination of two contrasting approaches. First there is the high level technical assessment and plan. Second a learning from the local people about their perceptions, current practice and aspirations. The viability of the first depends upon a full understanding of the second. A two way education is necessary.

David M. Ball (Environmental Resources Analysis Ltd., 5 South Leinster Street, Dublin 2)

Below are a number of areas where the high level technical and local experience overseas would have a bearing on groundwater development in Ireland in response to a change in climate.

1. There are much clearer and well defined water rights. There maybe no legislation and in many areas the rule of law does not apply. Tribal law or folklore in its place is very strong because water is vital. Life, journeys and annual cycles are planned around water availability. Water rights usually relate to a community, a tribe or a family. They protect the owner of land and water but they also protect the community and environment. There is a strong sense of community particularly outside towns and cities.

2. The relative scarcity of water means that deep ancient water is often developed. This is something we seldom consider in Ireland. The impact of developing deep water and the need for careful planning to avoid numerous potential disadvantages means that hydrogeologists become involved in much more complex drilling, testing and analysis. For example, environmental isotope studies.

3. There are two forms of agriculture in dry areas overseas; rainfed and irrigated. Rainfed usually provides a single cereal or staple crop. We practice rainfed agriculture in Ireland. Irrigation enables year round cultivation and up to 4 crops. The scale of irrigation varies enormously; ranging from handwatering of vegetables to massive centre pivots with a span of one kilometre.

4. Conservation of water. We do not need to look to say the Sahel to learn about conservation and multiple use of water. It is a practice throughout Europe. Here there is still a residue of the political perception that the whole country is a great floating bog that needs draining as rapidly as possible.

Conservation overseas involves:

(1) Reduction in demand (man, industry, animals, plants).

(2) Reduction in waste (unnecessary losses for example effluent and evapo-transpiration).

(3) Changes in surface water/groundwater storage or impoundment methods.

(4) Inducing greater natural recharge.

(5) Artificial recharge.

(6) Water system management techniques (eg coping with saline drainage water above a body of fresh groundwater.).

(7) Recycling or multiple use of water.

Superficially these techniques may sound sophisticated but they are all practiced at a very simple level by individuals or communities in the Overseas.

The changes in practice in Ireland will result from a change in perception <u>and</u> force of circumstances.

IMPLICATIONS OF CLIMATE CHANGE FOR AGRICULTURE

T Keane, Meteorological Service

INTRODUCTION

There is a considerable body of evidence which points towards climate change as having important effects on agriculture, yet there is no certainty as to what these effects will be - some changes are likely to be beneficial while others may have a negative impact especially at a regional level. Increases in production and the possible introduction of new crops may follow warming at mid to high latitudes of the world but decreased production is likely in the warmer core production regions of the US and southern Europe. Problems for agriculture in Ireland due to the onset of climatic extremes may concern the growing season, land trafficability, poaching, pollution, erosion. Other matters should relate to winter chilling, crop yield and yield quality. Changes in farm management may also have to be met due to small but important changes in timing of farm operations.

CLIMATE CHANGES IN IRELAND

Ireland lies in the middle latitudes well embedded in the climatic temperate zone with a prevailing westerly airflow. It has an oceanic climate (Rohan 1986; Keane, 1986). Situated off the European continent, however, any change of climate that should occur in this country may to some degree reflect that postulated for western Europe. Table 1 shows some of the climatic changes that may affect Ireland over the next 50 years based on data for temperate latitudes off western Europe (Report of Commonwealth Group of Experts, 1989; IPCC, Working Group II (draft report, 1990, restricted circulation)).

Changes in CO_2

Plant growth depends on absorption and fixation of CO_2 and its conversion into plant tissue. A doubling of CO_2 in the atmosphere can potentially increase growth of cereals by 35 per cent, maize by 16 per cent, tomato by 13 per cent and clover by 4 per cent. However higher temperature accelerates development and shortens the growing period of the plant.

Table 1 Possible Climate Changes in Ireland over next 50 years deduced from Changes Postulated for Western Europe

Parameter	Winter	Summer	Confidence ranking	Comments
CO_2	-	-	1	Pre-industrial doubling by 2030.
Temperature	+(2.0-3.0)°C	+(1.0-2.0)°C	2	Highest increase in winter
Evapo(transpi)ration	+(10-15)%	+(5-10)%	3	Increase follows temperature rise (5% per 1°C)
Precipitation	+15%	+5%	4	Less certain; more intense rainstorms especially in summer
Soil Moisture	Longer duration of field capacity	Increase in drought spells	5	Depends on rain/Evap balance
Wind	Reduction of westerlies		6	Fairly likely
Radiation	No change or less	±0% West +5% East	7	Uncertain
Humidity	High	More humid spells	8	Uncertain

Changes in Temperature

Excepting CO_2 the most likely change is for an annual increase in temperature of over 2°C in the latitudes 30°N to 60°N, highest in winter, least in summer. Consideration of the seasonal distribution leads to a lengthening of the growing and frost-free seasons and a reduction in cold temperature spells for winter chilling.

There will be an effective shift of the growing season northwards by 150 to 200 km per degree of warming and a shift to arable agriculture of about 150 - 200m in altitude. In the maritime areas of northwest Europe, yields of indeterminate crops such as grass and potatoes would tend to increase (+10% and +50% respectively) under higher growing season temperature assuming sufficient increases in precipitation to counter higher rates of evaporation.

Maize is a crop of particular concern in the event of a climate warming. In the context of the present climate maize may only be grown successfully in the southern half of the country to a stage suitable for silage 9 years out of 10. This does not compete with the grass crop in Ireland. Grain maize may be grown successfully in a better than average year in the southeast. But in a warmer climate the crop may be capable of competing with grass and cereals. Another crop near the limits of outdoor production in this country is the tomato requiring an annual heat energy input comparable to that of maize - it too should benefit from climate warming.

Evaporation, Precipitation and Water Balance

Based on the principles of energy, it follows that for every degree of warming there will be at least a 5 per cent increase in potential evapotranspiration. Therefore up to 15 per cent increase in potential evapotranspiration in winter and 10 per cent in summer is possible. The changes in precipitation are less certain. A likely eventuality would be for an increase in precipitation of about 15 per cent in winter and 5 per cent in summer. Another aspect of the change in precipitation is that rainfall events are likely to comprise of more intense storms rather than frequent prolonged and less intense falls.

The current balance between annual precipitation and potential (Penman) evapotranspiration is shown in Figure (1 a, b). The excess of precipitation over evapotranspiration is almost double at Claremorris whereas both parameters are of the same order of magnitude at Dublin Airport. The summer situation is of particular interest as much of the year's evaporation takes place in the warm season. A 5 per cent increase in summer rainfall and a 10 per cent increase in evaporation would lead to an increase in the moisture shortfall. Thus, especially in the east, the increase in evaporation during summer would often lead to a large negative imbalance in the available moisture, an attendant increase in soil moisture deficit, and a greater risk of more frequent drought. Irrigation of crops, particularly in the south and east may become a more common practise in this country.

Radiation

Models are not in agreement with respect to changes in radiation. Due to increased cloudiness and moisture from the Atlantic no great change in radiation receipt should take place in the west. However given a rise in summer temperature and more concentrated rainfall events, it is conceivable that radiation receipts will be enhanced by at least 5 per cent in the east. As a result of increased temperature and radiation, growth rates will accelerate. There will, however, be a shortening of the growing season/life cycle due to the increased temperature and radiation which would have the effect of reducing field yield. Benefitting from the earlier times of harvesting, for example sugar beet which is now harvested in October and November, quality would improve and losses would be reduced from the better trafficability and soil conditions.

CONSIDERATION OF SOME OF THE IMPACTS

Water Table

Because of increased rainfall in winter and spring there would have to be changes in the timing of various spring farm operations such as ploughing, fertilizing, beginning of grazing, etc. The effect of water table level on grassland farming as analysed by Brereton (1989) is relevant in the context of a wetter spring. Using a grass herbage production model he showed that some 30 per cent less stock can be supported on a wet soil compared with a dry soil - turn out is delayed in spring and the feed carrying capacity is less.

Assuming a 2°C rise in mid-winter temperature and no change in summer temperature, 25 per cent increase in annual rainfall and a decrease of 25 per cent in sunshine, Brereton (Teagasc, Moorepark; personal communication) showed for the southeast of Ireland that despite increased yields in early spring, turn-out date would be delayed by 30 days due to delayed drying of the soil. The season would also end earlier in autumn. There would thus be difficulties attending harvesting and utilization (grazing/silage making) of the increased herbage produced. Conditions in the wetter areas of the west would be more serious. While the meteorological parameters used in the above exemplification, especially in late spring and summer, may be over persimistic, nevertheless they do indicate new difficulties for the farmer in a changed but wetter climate.

Potential for Pollution

Intensive farming gives rise to pollution potential from higher concentration of nutrients, chemicals, silage effluent and farm waste. Rainfall is one of the important variables in creating pollution risk to the environment. Runoff from land is likely if heavy rain storms follow spreading of slurry on land (Sherwood, 1985). Runoff depends on soil type being greatest from heavy soil while infiltration risks are greater in the lighter soils. If climate change implies more frequent high rainfall events during the growing season, the periods for the safe spreading of slurry may be diminished (Figure 2). On the other hand if drought inhibits summer growth the fraction of fertilizer to be leached in the lighter soils over the following winter is greater (O Carton, Teagasc, Johnstown Castle, Wexford; personnal communication).

Flooding and Runoff

There will be increased risk of flooding in low lying areas and areas of high water table where the enhanced and heavier rainfall events lead to water spill-over from adjoining rivers, or from higher lands with impervious soils. Runoff risks are greatest from areas of climatic peat and soil of low hydraulic conductivity ($<$10mm/day in the subsoil) especially on slopes. Seasonal runoff during extreme wet periods may occur from basin and cutover peats and areas of high water table which are flat or gently undulating. In sandy soils or areas that are well drained the risk of runoff will be low (T Gleeson, Teagasc, Kinsealy; personal communication).

Forestry

The effects of changes of climate on forestry have not been greatly evaluated. Improved growth would result from increased CO_2 and increased temperature. Boundaries would shift particularly in respect to the altitude at which sowing would be possible (IPCC, 1990). While the west may have increased rainfall throughout the year, Sitka spruce (our most important commercial species) might become stressed on certain eastern and southern area sites in terms of drought (E Hendrick, Coillte, Bray; personal communication).

Forest fires may also become a hazard with increased frequency of drought in early summer. As it is uncertain as to what the future climate may hold as regards wind it is difficult to predict windthrow damage. However if the climate becomes more unstable, then the incidences in autumn of intense concentrated storms from the lower latitudes of the Atlantic may increase thus accentuating the negative impact of climate change.

Diseases

The mild winters would favour increased aphid populations leading to crop defoliation and thus reduced growth of most plants, e.g. cereals, root crops, forestry. The wetter winters and springs would lead to more eyespot and Septoria and other wet season diseases. The greater frequency in southerly winds may increase the number of arrivals of moist airmasses to this country during summer, particularly in southern and western areas, thus enhancing the risks of potato blight. Increase in hot humid spells in summer would favour brown rust in ereals. Some continental diseases especially animal diseases may also spread to Ireland.

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Says an increase in winter PP (at Phoenix park) 1880 -> 1950.

Copy of overheads

T Gleeson, MCP.
Areas with [illegible] serious [illegible]
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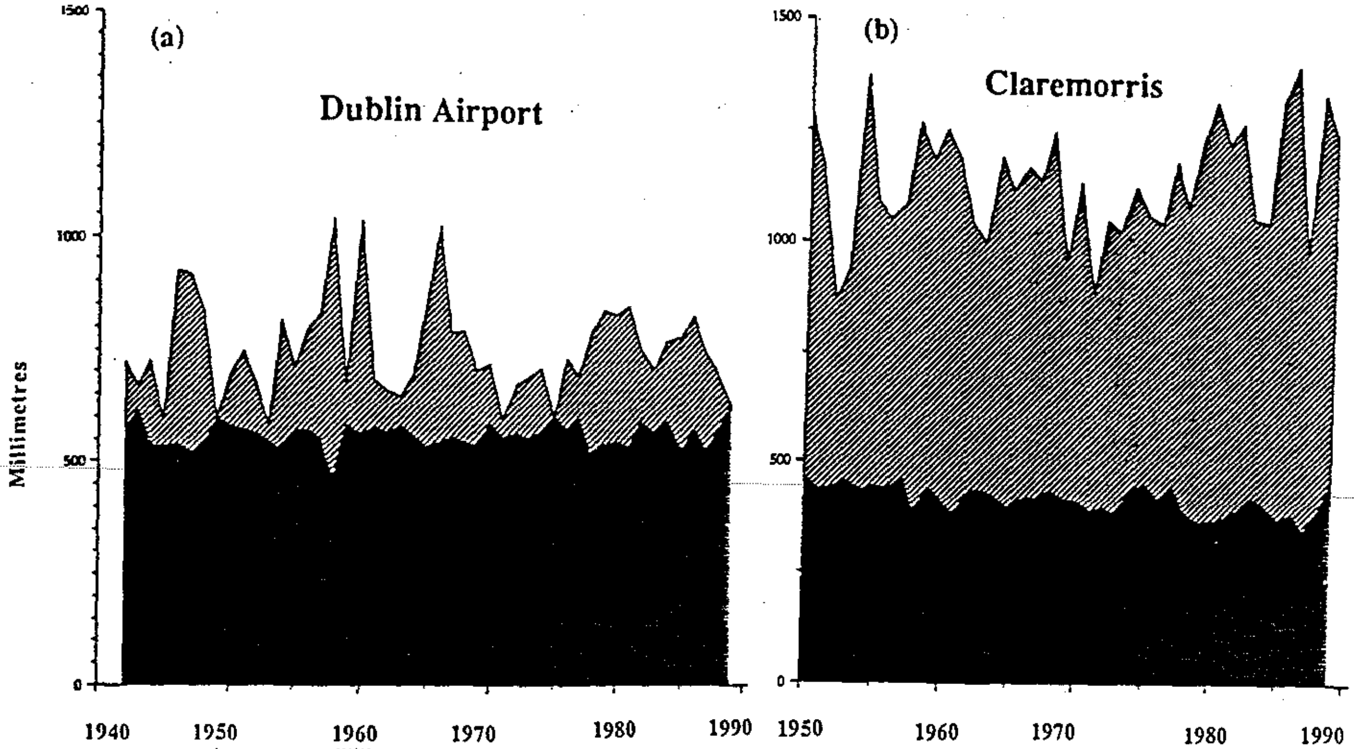

Fig. 1 Annual Rainfall [hatched] and Potential (Penman) Evapotranspiration [black] amounts at (a) Dublin Airport (1942- 1989) and (b) Claremorris (1950-1989)

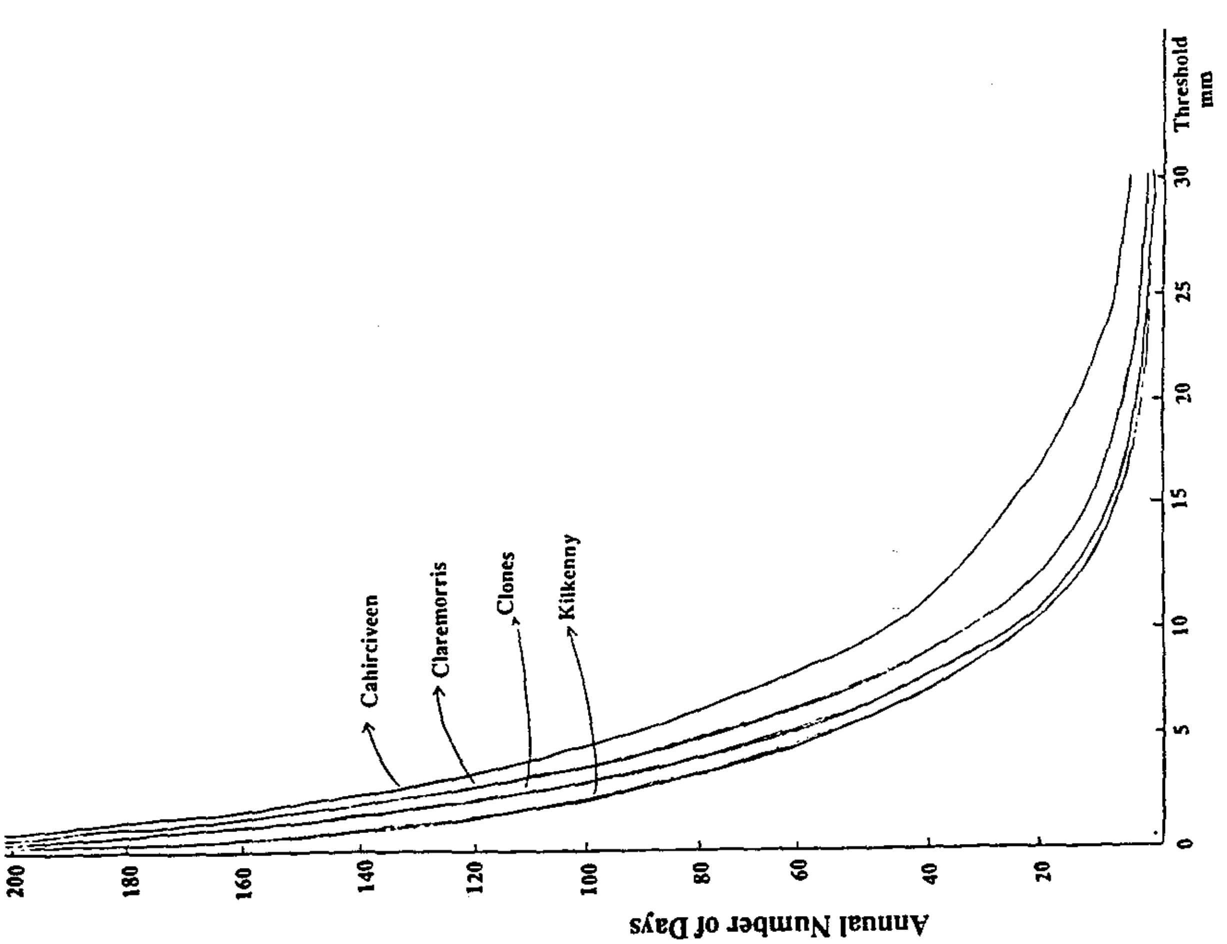

Fig.2 Annual Frequency of Days with Precipitation of the given Threshold

THE IMPLICATIONS OF CLIMATE CHANGE FOR COUNTY WEXFORD

P. CALLERY, COUNTY ENGINEER, WEXFORD COUNTY COUNCIL

1. INTRODUCTION

In this short paper I will refer specifically to County Wexford. The main effects of climatic change in Wexford will be felt in the coastal zone. Wexford has 250 km of coastline, with 130 km of sandy beaches. It is a popular seaside tourist county with four Blue Flag beaches - Duncannon, Rosslare, Curracloe and Courtown.

2. WINTER STORMS 1989/'90

The violent storms since the 16th December give an indication of conditions which may be more frequent in future.

The following are examples of the damage:

Part of a county road at Clone was washed away due to cliff erosion. Courtown Beach experienced extensive erosion - a dune recession of 20 metres in some locations. At Ardamine Beach one holiday home was washed into the sea and rock defenses at the base of the dunes were overtopped. Extensive pier damage took place at Cahore and Kilmore Quay. The dune system along the coastline from Ballyconnigar to Wexford Harbour took a severe battering. There is danger of a breach in the dune system which would flood the reclaimed North Slobs. Rosslare Strand was particularly badly affected. The waves broke on the playroom at the rear of Kellys Hotel. Half of Rosslare Golf Course was inundated and the dunes were extensively eroded.

Holiday homes at Ballyhealy are now exposed to the sea as a result of dune erosion. The Ballyteigue Burrow System, which is under the control of the Office of Public Works, was breached in a number of places almost causing catestrophic flooding. 2,000 hectares of reclaimed agricultural land are immediately in danger. Extensive erosion has taken place at Cullenstown because of the changing course of the adjacent river outlet.

The total immediate repair bill for the County is £6.4 million, including the Rosslare Capital Scheme.

3. ANTICIPATED RISE IN SEA LEVEL

Estimates of future sea level rise due to global warming vary considerably. Figures such as a rise of one metre in level over the next 50 years have been suggested. Studies in America indicate that a rise of one metre would mean a recession of the coastline of 100 metres. Such an occurrence would have major consequences for County Wexford. The County Council is aware of these implications and have recently commissioned Consultants to prepare a Coastal Development Plan which will address this issue particularly. It would be totally uneconomic to carry out protection works on the whole coastline and, therefore, it will be necessary to identify strategic areas for protection.

A number of these areas are as follows:

3.1 Wexford Town

Wexford is located on the estuary of the River Slaney and is vulnerable to wave attack from Easterly storms. The Wexford Main Drainage Scheme (£20m) is awaiting Ministerial sanction to be advertised for tender. The scheme involves a quay extension which will incorporate a 1.0m high reflective wave wall. This will provide protection for the low lying areas of the town which, even now, are prone to flooding.

3.2 Rosslare

A major coast protection scheme is planned at an estimated cost of £6 million. This scheme involves the construction of 14 rock groynes at intervals of 400 metres. A new beach will be provided by importing 1 million tons of suitable sand and filling between the groynes. This scheme will raise the existing beach level and move the High Water Level away from the coastline. Work has already commenced on a stone revetment to protect eroded dunes along Rosslare Golf Course.

3.3 Courtown

This is a Blue Flag beach in North County Wexford. The County Council have commenced work on restoring the dune system. Rock armouring is being placed at the base of the dunes. Damaged dunes will be regraded and stabilized by planting with marram grass and buckthorn. A dune management scheme is being provided whereby pedestrian traffic will be limited to specific access points. Extensive fencing will be carried out to enable the dune system to be rehabilitated.

3.4 Piers and Harbours

Urgent repairs are necessary to most of the piers and harbours in the County as a result of the winter storms. Short-term repairs are being carried out at Kilmore Quay costing £90,000, and the County Council, together with the Department of the Marine, have a scheme costing £2 million planned for extending and improving the harbour. It is essential that additional armouring is provided for harbours and piers in order to withstand the anticipated higher seas.

3.5 Coastal Dune System

The dunes in County Wexford, in addition to forming a natural habitat for flora and fauna, protect extensive areas of low lying agricultural land. Many millions of tonnes of sand were eroded from the system last winter. In the Netherlands the response to this problem has been to dredge sea sand from deep in the North Sea and pump it ashore. If we are to maintain our sea defences in sand dune areas, I consider that we may have to do the same.

4. NATIONAL PROBLEM

The examples I have given from County Wexford are repeated to a greater or lesser extent in all the Maritime Counties. Wexford County Council have taken the initiative of calling together the Chairmen and County Managers of all these Counties in order that a submission can be made through the Government to the E.C. for coastal erosion funding. Under the present Structural Fund Aid for Ireland there is no money for coast erosion. However, the ENVIREG Programme, on the initiative of the E.C. Commission, may provide the necessary access to funding for Ireland. The first meeting of the maritime counties has now taken place and, hopefully, this has been the first step in formulating a national strategy for coastal protection.

5. CONCLUSION

Climatic changes have major implications for our country, particularly in the coastal area. The cost of the necessary protection works will be great, but by acting in time the cost can be distributed over the coming years. Wexford County Council is aware of the changes that are coming and is planning to meet this challenge.

EXTREME FLOODS ON E.S.B. HYDRO CATCHMENTS

Thomas A. Hayes B.E; M. Eng. Sc.; C Eng. M.I.E.I.

1. INTRODUCTION

During the past five years (1986-1990) some of the largest floods on record have been experienced at a number of catchments on the E.S.B. Hydro-Electric system. Two of these events occurred in August 1986.

On the River Lee a flood with an estimated return period of 250 years occurred on 5-6 August - while on the River Liffey a flood with return period also of 250 years occurred in the Upper Liffey catchment on 25-26 August. More recently - in February of this year (1990) one of the largest floods on record since the commissioning of Ardnacrusha was experienced in the River Shannon.

Each of these three catchments, together with the dams on them, have differing flood retention and discharge characteristics. These will be examined in some detail in the case of the River Liffey. Firstly, a brief comment is passed on these exceptional floods on the Rivers Shannon and Lee.

2. RIVER LEE - FLOOD OF 5-6 AUGUST 1986.

As a result of the storm of the 5-6 August 1986 the largest flood on record occurred on the Lee catchment. It is estimated that the annual probability of this flood is about 1 in 250. The peak inflow to Carraigadrohid reservoir was 575 cumecs resulting from a mean areal rainfall over the contributing catchment of 92mm occurring in a period of 22 hours. However, as a result of the moderating effect of the dam and reservoir at Carraigadrohid, the peak discharge there was reduced to 450 cumecs. The peak inflow into the reservoir at Inniscarra downstream was 504 cumecs with a resultant peak discharge of 331 cumecs into the Lower Lee Valley. Considerable damage was done in the upper part of the catchment especially along the River Sullane which flows through Macroom and feeds Carraigadrohid reservoir. The regulation of the flood through Inniscarra and Carraigadrohid reservoirs prevented flooding of a more serious nature downstream to Cork City. In fact, we have estimated that the water levels at the Water Works Weir at Cork city boundary would have been 0.7m higher had there been no dams on the Lee catchment.

3. RIVER SHANNON - FLOOD OF FEBRUARY 1990

The largest flood on record on the River Shannon for at least 60 years was experienced in February 1990. It did not result in the highest peak recorded inflow to Lough Derg, the lower lake, but the volume of inflow over a period of weeks resulted in the highest recorded level in Lough Derg since the Shannon scheme was commissioned. The peak level in Lough Derg during this flood was 34.16m.O.D. whereas the previous highest recorded peak was 34.12m.O.D. in December 1959.

The flood also produced the highest recorded level in Lough Ree (39.12m.O.D.), the previous highest recorded level having been 39.09m.O.D. in December 1954.

Levels downstream of Athlone, where the worst affects of Shannon flooding are experienced annually, were approximately the same as the peak levels recorded in the 1954 flood.

The River Shannon with its series of natural lakes and channel restrictions is largely self-regulatory. Therefore, taking the river as a whole, the existence of Parteen Weir and Ardnacrusha dam have very little influence on its discharge capacity. However, the head race and tail race by-pass areas liable to flooding between Parteen Weir and Limerick city, so that damage that would otherwise occur with a flood of this magnitude is very much reduced along this section of the river.

4. RIVER LIFFEY - FLOOD OF 25TH AND 26TH AUGUST 1986

4.1 River Liffey Catchment

There are three dams on the River Liffey: Pollaphuca, Golden Falls and Leixlip.

The upper catchment from the source to Pollaphuca, with an area of 308 sq.km is comprised of steep mountainous countryside rising from an elevation of about 183m.O.D. at the dam to a maximum elevation of 760m.O.D. at Kippure. The average annual rainfall, for the period (1951-1980) was 1390mm, with a variation from 925mm to 2000mm over the catchment. Pollaphuca Dam impounds a reservoir with a surface area of 20 sq.km. The capacity of the reservoir, which is $158 \times 10^6\ m^3$ at normal high water level of storage, is approximately equal to 50% of the annual average flow for the catchment. The upper reaches of this catchment consist of a blanket bog overlying granite rock, which gives rise to its flashy nature.

Golden Falls Dam is situated two kilometres downstream of Pollaphuca. The intermediate catchment to the dam is very small with an area of 6 sq.km and the associated reservoir has negligible flood storage. Therefore the inflow to this reservoir is effectively equal to the discharge from Pollaphuca.

The middle catchment, between Golden Falls and Leixlip, comprised of an area of 534 sq.km, is flat and at an elevation of between 60m.O.D. and 90m.O.D. Annual average rainfall for the period (1951-1980) was 825mm with little variation across the catchment, from 750mm to 925mm. In contrast to the Upper Catchment this catchment exhibits a slow response during rainstorms. There are deep sand and glacial deposits throughout the catchment. Measurements by the Geological Survey of Ireland indicated rock to be 75m below the surface in some locations, such as the Curragh. A more detailed description of the glacial origin of this sub-catchment is given in other publications. From Leixlip the Liffey continues to Dublin city and the Irish Sea.

4.2 Meteorological Conditions Leading to Storm of 25th-26th August 1986

The unusually severe rainstorm which occurred was due to the large mass of warm moist air left over from the spent hurricane "Charlie" coming into contact with cooler North Atlantic air just off the coast of Ireland, causing it to turn into a deep depression. This depression centered on the East Coast of Ireland for a period of 24 hours causing the severest rainstorm in certain areas experienced in living memory. The 1 day rainfall values recorded at five rainfall gauges in the environs of Dublin were the highest ever recorded. In excess of 200mm of rainfall is estimated to have fallen in 24 hours in upland reaches of the Dodder/Dargle catchments.

Only one automatic gauge functioned satisfactorily in the Upper Liffey Catchment - Glenbride Lodge. A storm profile based on this automatic gauge record and all available daily gauges around the Upper Catchment was constructed. The total mean areal rainfall was estimated to be 117mm with a peak hourly rate of 10mm. In the middle Liffey catchment the total rainfall was estimated to be 64mm with a peak hourly rate of 5.5mm. Obviously, the worst of the storm was not experienced on the Liffey catchment.

4.3 Resultant Flooding in Liffey Catchment

During the flood there was no discharge through the spillway or turbines at Pollaphuca dam, i.e. the total flood was stored comfortably in Pollaphuca reservoir. The inflow volume to Pollaphuca reservoir was 27 million cubic metres resulting in a rise in level of 1.37m. The peak inflow was 445 cumecs which is the second highest on record, the highest being 568 cumecs which occurred in November 1965.

As Golden Falls reservoir is immediately downstream of Pollaphuca dam there was no measurable inflow and consequently no discharge through the dam.

The inflow to Leixlip reservoir, in the absence of discharge at Golden Falls, is attributable to the intermediate catchment between Golden Falls and Leixlip only. Despite the heavy rainfall on this area of the catchment (64mm in 24 hours), the peak inflow to Leixlip reservoir was only 47 cumecs, as compared with the maximum recorded inflow of 155 cumecs in the flood of December 1954.

This apparent anomaly is due to the unusual storage feature of this catchment which has been identified and investigated in some detail. The runoff from rainstorms is abnormally variable, and points to the existence of substantial underground storage, presumably in the wide - spread gravel deposits which underlie the area. The low runoff from this rainstorm would suggest that much of the precipitation went to recharge ground-water storage. The total inflow volume to Leixlip reservoir was only 5.2 million cubic metres.

Downstream of Leixlip, severe floods were also experienced on tributaries feeding the Lower Liffey basin. The most spectacular of these was probably the Dodder. At Bohernabreena the peak flow was estimated to be 91 cumecs while at Orwell Bridge near the outfall to the Liffey estuary it was between 215 and 254 cumecs. (Estimated Return Period = 1:500 years).

4.4 Effect of Dams on River Liffey during Flood of August 1986

It is clear that Pollaphuca reservoir acted as a flood relief reservoir for the Middle and Lower Liffey Valley and indeed Dublin city. If Pollaphuca dam was not constructed a flow of approximately 400 cumecs would have been recorded at Leixlip. This would have caused serious flooding along the Middle Liffey Valley. Together with the discharge from the Ryewater, which feeds into the Liffey just downstream of Leixlip dam, it would have resulted in major flooding from Leixlip to Dublin city.

5. CONCLUSIONS

It is clear that E.S.B. dams on the River Lee and Liffey exert a major and positive control on the intensity of flooding experienced in lower catchment areas during major floods. In the case of the River Shannon this influence is less significant but still positive. The more extreme a flood becomes, though, the less influence a dam has on regulating it, until a point is reached where the peak flood inflow to a reservoir has to be discharged in the interest of dam safety.

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RECENT WATER SUPPLY EXPERIENCE OF CLIMATIC EXTREMES IN ENGLAND AND WALES

Rick Brassington,
Regional Water Resources Manager

National Rivers Authority, North West Region,
Warrington, England

Summary

Climate change caused by global warming is an important topic for all governments. These changes are likely to include a variation from the present average annual rainfall and its seasonal distribution; alterations in weather patterns; and a rise in sea level. These will all have implications on the availability of water resources and the frequency of river and coastal flooding. The British research programme into climate change is discussed and examined against recent experiences of drought. Possible strategies for water resources management to overcome these problems are discussed.

Introduction

The average man-in-the-street must already think that climate change has happened. Last winter was one of the mildest since records began. Temperatures were so warm that grass hardly stopped growing and there was very little frost or snow. The early part of the winter was dry, but from mid-December it was exceptionally wet. There were a number of violent storms which caused damage to trees and buildings. The previous winter (1988/89) was also mild and had the strongest winds (the so called "Hurricane") recorded in over 200 years. By contrast, the summer of 1989 was very dry with water shortages being experienced in most parts of England and Wales, particularly in the south and east. The majority of scientists would agree that climate change appears to have started because these unusual events are all compatible with the broad pattern which is expected. There are a few who dispute that climate change is occurring, but they are in a minority. Where scientists do not agree is in the predictions of exactly what these climate changes will mean in terms of a re-distribution of precipitation both geographically and seasonally, and the amount by which sea levels are likely to rise.

The starting place for making predictions on climatic change depends upon the construction of a computer-based Global Circulation Model. The movements and workings of the atmosphere is a bewilderingly complex system and in order to model it, it is estimated that computers are required to be 1,000 times more powerful than the best which are available today. It is anticipated that such computers will not be available before the end of this decade. The lack of a Global Circulation Model means that the predictions made by one group of workers will be different in detail to those made by another group. Whatever the detail, however, it is possible to estimate a broad range for changes in precipitation distribution and sea level rise. It is therefore possible to examine and plan strategies to combat these changes.

There have been environmental events in British history that have posed significant economic and social problems. Examples include the sequence of severe winters (during the 15th, 16th and 17th centuries) known as the Little Ice Age, and the year without a summer in 1816. Recent examples include the droughts of 1975/76, 1984 and 1989 and the increase in radioactive fall-out resulting from the Chernobyl nuclear power station accident in 1985. Many of these changes, particularly the weather-related events, represent the extremes and range of variability around mean values of temperature, rainfall, wind-speed and solar radiation which, taken over decades, remain relatively stable.

From recently observed environmental changes such as the rise in atmospheric carbon dioxide and fluctuations in the polar stratospheric ozone have reached values which, so far as is known, the global system in its present form has not previously attained. There are predictions from computer models that these changes would lead to other major environmental perturbations such as global warming, rising sea level, changing geographical distributions of precipitation and solar radiation and increased ultra-violet radiation at the earth's surface. The predictions include major long-term alterations to mean values and to associated variability far outside man's previous experience in the last 20,000 years. However, these predictions are all based on assumptions and very inadequate data. If man is to cope constructively with environmental change, then research must have three main objectives. The first is improved predictions of long-term environmental scenarios based on more extensive observations and of environmental systems and on enhanced computer models. The second is to improve predictions of the impact and timescale of such scenarios upon man, and his resource needs for water, food, energy and minerals and on society and political systems. The third is a need to communicate the results.

Environmental Research in the United Kingdom

An immediate aim of global environmental research in the UK is to predict the consequences of changes in the global environment for the national environment. It is already apparent that sea level is rising with effect on coastal erosion, erosion control and salt water intrusion into surface and ground waters. It is already confirmed that average temperature has increased by 1 C since the beginning of the century. Together, these changes might be expected to lead in decades to changes in natural habitats and to wildlife, though the long-term records are not sufficiently adequate to relate any faunal and floral changes to environment change. Increases in methane, lead, sulphur dioxide, nitrogen oxides and ozone in the atmosphere have also been documented with some associated effects on buildings, human health and vegetation. Further changes in these environmental parameters are anticipated. Changing climate patterns resulting from a global warming, induced by rising levels of carbon dioxide, methane and CFCs, could have a major effect on the British Isles. Such a warming could cause a rising sea level from the thermal expansion of the oceans and later, should the warming continue, from ice-cap melting. The UK already spends some £200M per year on the coastal defences which demonstrates a need to protect low-lying areas of eastern and southern England as well as many of the major cities including London which are particularly vulnerable. Any substantial environmental change will effect large sectors of the UK economy. There have been several recent studies to examine the impact of environmental change on the economy with particular emphasis on agriculture, civil engineering, transport, energy and insurance. The studies are based on the assumptions about future environments with no certainty about whether or when they occur. The conclusions are that there would be major changes in many aspects of the economy, but that none are likely to be disastrous. It is also clear that the different sectors of the economy require different amounts of warning time to adjust to environmental change. Thus, there is an immediate need to make a thorough examination of alternative energy sources with respect to environmental effects because investment in power stations must be planned now in relation to electricity production for the next 25-30 years. Fossil fuel burning may have to be limited or the balance of energy sources modified if carbon dioxide emissions are to be reduced. Nuclear power may be substituted if questions related to safety, radiation control and radioactive waste disposal can be answered satisfactorily. Benefits which could be derived from renewable energy sources also need to be taken into account. Other industrial sectors such as building construction and flood control also require immediate consideration. Buildings erected now will have a life expectancy of at least 50 years, well into the time when environmental change may dictate their modifications. Similarly, because sea level is already rising, flood control measures such as the Thames Barrier require continuing appraisal and attention. In some economic sectors, such as agriculture and transport, the effects may be accommodate within a much shorter time. Other sectors such as insurance are also likely to be affected. All impact studies so far have been very preliminary and need to be extended when clearer indications of local or regional change emerge from global environmental research.

Manufacturing is affected by changing environmental conditions because it not only uses non-renewable resources, but it is the origin of many environmental changes such as the depletion of the stratospheric ozone due to CFC manufacturer, and the increased production of methane. Increasing international pressures for controls and the substitution of "environment friendly" products is likely to take place and the industry must be able to keep abreast of such trends which are likely to be driven by results stemming from global environmental research. The Montreal Protocol represented a significant albeit first step in international actions. Other areas where international issues are likely to arise are in the use of fertilizers and pesticides and in many aspects of effluent and pollution control. Such concerns are likely to increase rather than diminish with the introduction of the Single European Market in 1992 and the establishment of European-wide environmental policy.

It is important for the manufacturing industry to know very early on in their product process cycles what future environmental factors require to be taken into account. It is expensive for industry to change its planning strategy or designs at a late point in the industrial cycle.

Global environmental research is important in providing data at a very early stage which should assist industry in producing products which, from the outset, are environmentally benign.

The government are co-ordinating climate change through the Department of Environment with other departments (such as the Ministry of Agriculture, Fisheries and Food) also involved. Much of the research is carried out by universities and by the research institutes which make up the National Environment Research Council (NERC). These include the Institute of Hydrology and the British Geological Survey.

THE NATIONAL RIVERS AUTHORITY

The National Rivers Authority (NRA) was established under the Water Act 1989 on 1st September 1989 as a pre-requisite to the Government's privatisation of the water industry in England and Wales. The NRA was established to carry out the "rivers functions" of the former ten regional water authorities, which comprise the control of water pollution, land drainage and flood defence, water resources management and protection, fisheries, recreation, conservation and navigation. The NRA has a small head office in London and is divided into ten regions based on the regions of the former regional water authorities.

Climate change is likely to impact on all areas of the NRA's activities. Consequently, the effect of climate change is included in the NRA's research and development programme. Priority is being given to the effects on water resources availability and river and coastal flooding. The latter extends to research on possible construction methods for flood control embankments. As the Department of Environment is taking a lead in funding research on the impact of climate change on water resources and flooding, the NRA is maintaining a close liaison with DoE and making a contribution to appropriate research projects. The NRA are ensuring that long-term hydrometric records are maintained to help judge the impact of climate change.

NRA research into the impact of climate change is not covered in detail in this paper. It is thought likely that river and coastal flooding will become more frequent, hence flood warning schemes which provide at least four hours' advanced warning of serious incidents will become more important. The flood warning scheme operated by the NRA-NW is described in Appendix 1 as an example of such systems.

THE USE OF WATER RESOURCES

Almost half the water abstracted in England and Wales is for public water supply. Of this, about half is supplied to industry and agriculture and the rest for domestic consumption. Throughout England and Wales, approximately one-third of public water supplies is derived from groundwater, with the remainder from river intakes and reservoirs. Figure 1 shows public water supply abstraction for each water plc area in England and Wales, split into groundwater and surface water. The greater dependence on groundwater sources in the south and east is due partly to the availability of good groundwater supplies from the Chalk, Greensand, Jurassic Limestone and Permo-Triassic Sandstone aquifers and partly from the gentler topography and relatively lower rainfall which result in a low availablility of surface water resources. This contrasts with the west and north of the country where a high rainfall and more marked topography lends itself to surface water abstraction. Locally, groundwater abstraction is significant, as can be seen if the quantities abstracted in the North West and Yorkshire regions are compared with those abstracted in Wessex and the Southern regions. Direct abstraction by industry is largely from surface water sources, with around 20% coming from groundwater. Licensed abstractions for agriculture are mainly from groundwater. This is largely because the abstraction licensing legislation exempts many surface water abstractions from requiring a licence.

1989 DROUGHT

The three month period from November 1988 to January 1989 were the driest this century, and following then February, May and June had much less than average rainfall. Each month from May until December (except October) had less than average rainfall. The period of dry weather ended to mid-December where, in most parts of the country, the last two weeks of December saw the average total monthly rainfall for the month. The prolonged dry weather caused river flows over much of the country to be well below average and in many areas groundwater levels were the lowest since the great drought of 1976. Indeed, in some parts of the country, the groundwater levels reached these minima at an earlier period in the year than was the case in 1976. The worst affected areas were the south coast counties, particularly Kent and Sussex, although serious problems extended across most of the country east of a line from the Bristol Channel to North Yorkshire. The rest of the country did not escape, however. For example, in Lancashire's Bowland Forest, normally a very wet area, June was the driest this century.

Water stocks recovered very rapidly during the second half of the winter which was exceptionally wet. In the east of England which relies very heavily on groundwater for public and private supplies, groundwater levels have not recovered to their seasonal normal level. It is anticipated that in this part of the country, ground conditions couldextend throughout 1990. Indeed, in East Anglia, some areas are likely to be hit harder than they were in 1989.

Water Saving Measures

Water authorities took water saving action by either restricting the quantities of water available for their customers or abstracting water in contravention of their abstraction licence conditions. In order to do this legally, water authorities need a Drought Order, for which they apply to the Department of the Environment. These Drought Orders permit water saving measures such as hosepipe bans and restrictions which forbid the use of water for fountains, washing buildings etc, and in the ultimate extreme, replacing domestic supplies with stand-pipes in streets.

Drought Orders also enable a water authority to reduce the compensation discharge from reservoirs or to abstract water when river flows are lower than would be normally permitted by a licence. This latter category of water saving measures impacts largely on the environment, rather than on the customer. A large number of Drought Orders were granted by the Department of the Environment to all the water authorities in England and Wales. The majority of these drought orders were to enable them to reduce compensation discharges rather than to reduce the supplies to their customers. Most of the Drought Orders expired around the turn of the year, but a few still remained in force until the end of March in the south of England.

NRA Policy

The Water Act 1989 gives the NRA the right to comment on all Drought Order applications, but as it was formed on 1st September 1989, at a time when the majority of Drought Order applications had already been made by the water authorities, the NRA was unable to have any significant influence. The NRA view is that where water saving measures require the use of a drought order then the impact on the customer and the environment should be equally balanced. As Drought Orders mean that abstraction licence conditions (which are designed to protect the water environment) no longer apply at the times of stress when they are most needed the NRA will be reviewing the yield of reservoirs and other water supply schemes when comparing these with the licences. In some instances it may be necessary for licensed quantities to be reduced. This may require the development of alternative water supplies.

Currently, each NRA region is reviewing the experiences of the Drought in detail before a national report is prepared.

THE IMPACT ON WATER RESOURCES

For the reasons given above, it is not yet possible to anticipate the detailed impact on water resources or decide on strategies to augment water supplies. Existing methods are likely to be applicable, some of which are considered here.

Water Supply Augmentation Using Groundwater

The relatively large volumes of water stored in some aquifers can be used to augment water supplies. This can be achieved by groundwater sources being used conjunctively with reservoirs or river intakes in that the surface water sources are used when there is abundant river flow available and groundwater is abstracted only in the summer at times of low flows. Alternatively, groundwater pumped from boreholes can be discharged into river systems to augment the summer flows in dry years. In this way direct abstraction can be increased from downstream river intakes for public water supply without the need for surface storage and as a bonus, the river benefits along its entire length by increased flow in dry summers.

An example of a conjunctive use is the Lancashire Conjunctive Use Scheme which is operated by North West Water (see Figure 2). This scheme is based on surface water abstraction from the River Wyre which has flows increased by water transferred through a tunnel at Abbeystead from the River Lune. It is also possible for water to be transferred into the system from the Thirlmere Aqueduct. These surface water abstractions are supported by groundwater pumped from the Permo-Triassic Sandstone in the Fylde. The groundwater element of this scheme has been thoroughly tested during both the 1989 and the 1984 drought. In 1984 the pumping started in May and continued all year following the Abbeystead explosion which rendered the tunnel unusable for that time. The main difficulty with using groundwater in this way is that customers object to fluctuations in water quality. They have relatively soft water when supplies are based on river water and hard water when groundwater is in use.

Since the last 1960's, thirteen schemes for augmenting river flows by groundwater have been developed. The schemes do not include those which are more truly classified as river compensation schemes which are designed to ameliorate direct borehole abstractions. Some of these augmentation schemes were very large, such as the Severn-Trent Shropshire Groundwater Scheme which when all its eight stages are implemented, will comprise seventy abstraction boreholes in an area of 830 sq.kilometres. Most of the schemes have been developed by the Regional water authorities but a scheme on the River Calder in West Cumbria is operated by British Nuclear Fuels Ltd.

Concept of Net Gain

Although not the case in all situations, a borehole located close to a river will quickly draw on river water or more commonly, produce flows by intercepting groundwater before it discharges naturally into the river as spring flow. Within a short time, the stream is reduced in flow by an amount which is equal to the borehole pumping rate. Boreholes located further away from the river however, will take longer to affect stream flows and it follows that having regard to the hydraulic characteristics of the aquifer and the size of its catchment, it is possible to site boreholes at a sufficient distance from a river to greatly delay the effect of their abstraction on streams flows. Discharges from these boreholes into a stream by a pipeline would boost river flows and this increasing flow (expressed as a percentage of the pumping rate) is termed "net gain". Conversely the amount by which natural stream-flows are reduced by pumping (again expressed as a percentage of the pumping rate) is termed "stream depletion". The aim of such augmentation schemes is to delay the main effect of pumping on stream flows until the following winter when the reduced flow will not be the problem. This is illustrated in Figure 3.

Before any new groundwater schemes are initiated, it will be necessary to assess the availability of groundwater issues, including the impact of climate change on recharge and carry out detailed flow-regime studies to assess the need for augmentation. The scope for such schemes may not be very large as the current level of groundwater development already causes streams to be depleted in many areas. This aspect of water resources development is giving rise to significant public concern and is usually being given a high priority by the NRA.

Saline Intrusion.

As the sea level rises, the potential for sea water to extend further inland up river estuaries or into aquifers is increased. This is likely to have a large impact on coastal groundwater abstractions and river abstractions on lower reaches. The latter problem could be addressed by raised weirs and sluices but groundwater problems are likely to be more complex. Initially, the groundwater flow systems must be investigated in detail and reliable aquifer models developed. These will be used to assess the impact of various scenarios in the abstraction regime. It is likely that strategies such as coastal pumping of saline groundwater to control the interface will be adopted in some cases.

CONCLUSIONS

Climate change will result in significant changes to the hydrological cycle which will impact on river flows and water resources. The UK Government and the NRA are both giving a high priority to climate change research. The NRA is particularly concerned on aspects of river and coastal flooding and on water resources. The possible ways of augmenting resources include the use of groundwater, but this is limited by the extent of existing groundwater development.

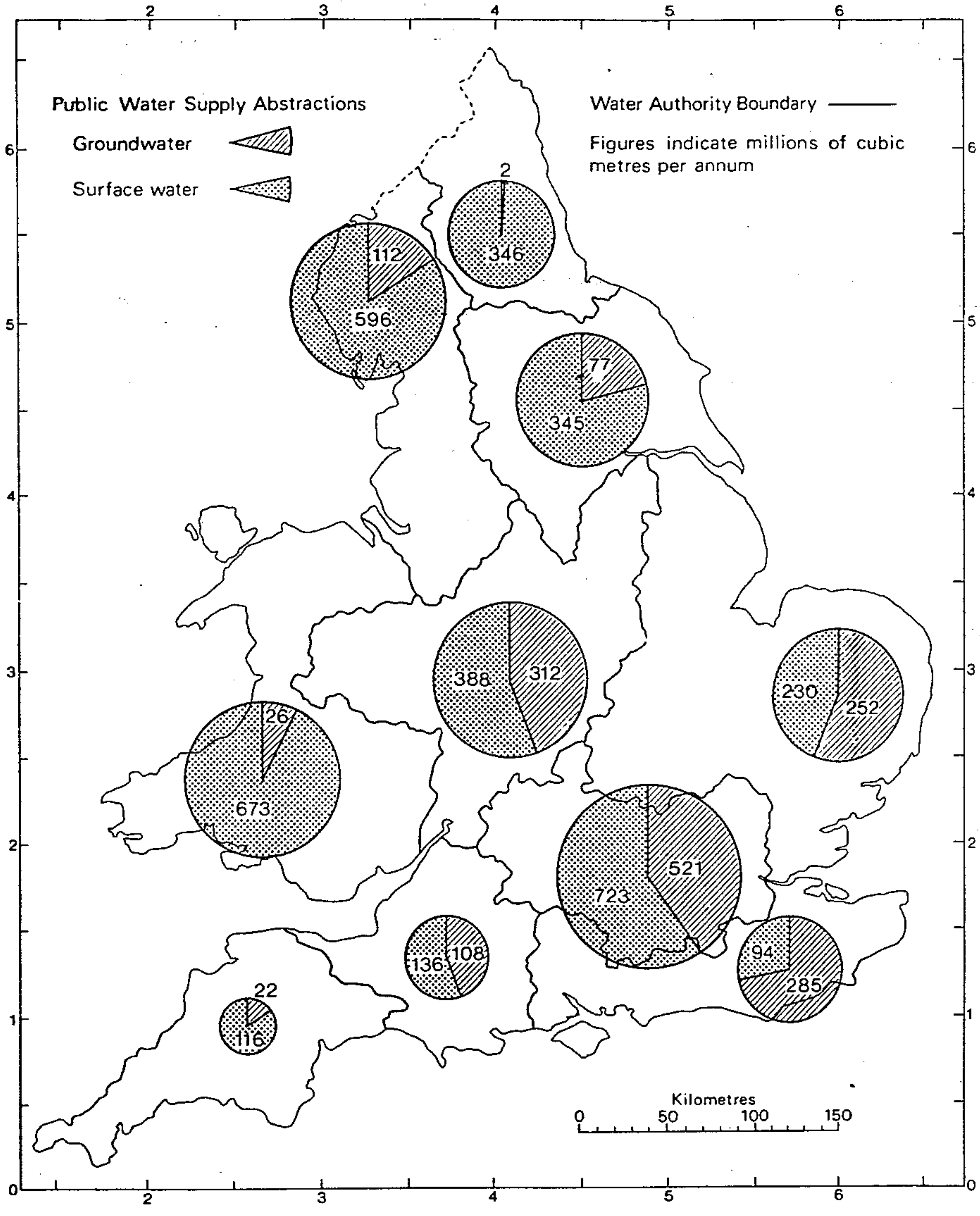

Fig I Groundwater usage for public water supply in England and Wales

(after Water Data Unit[1])

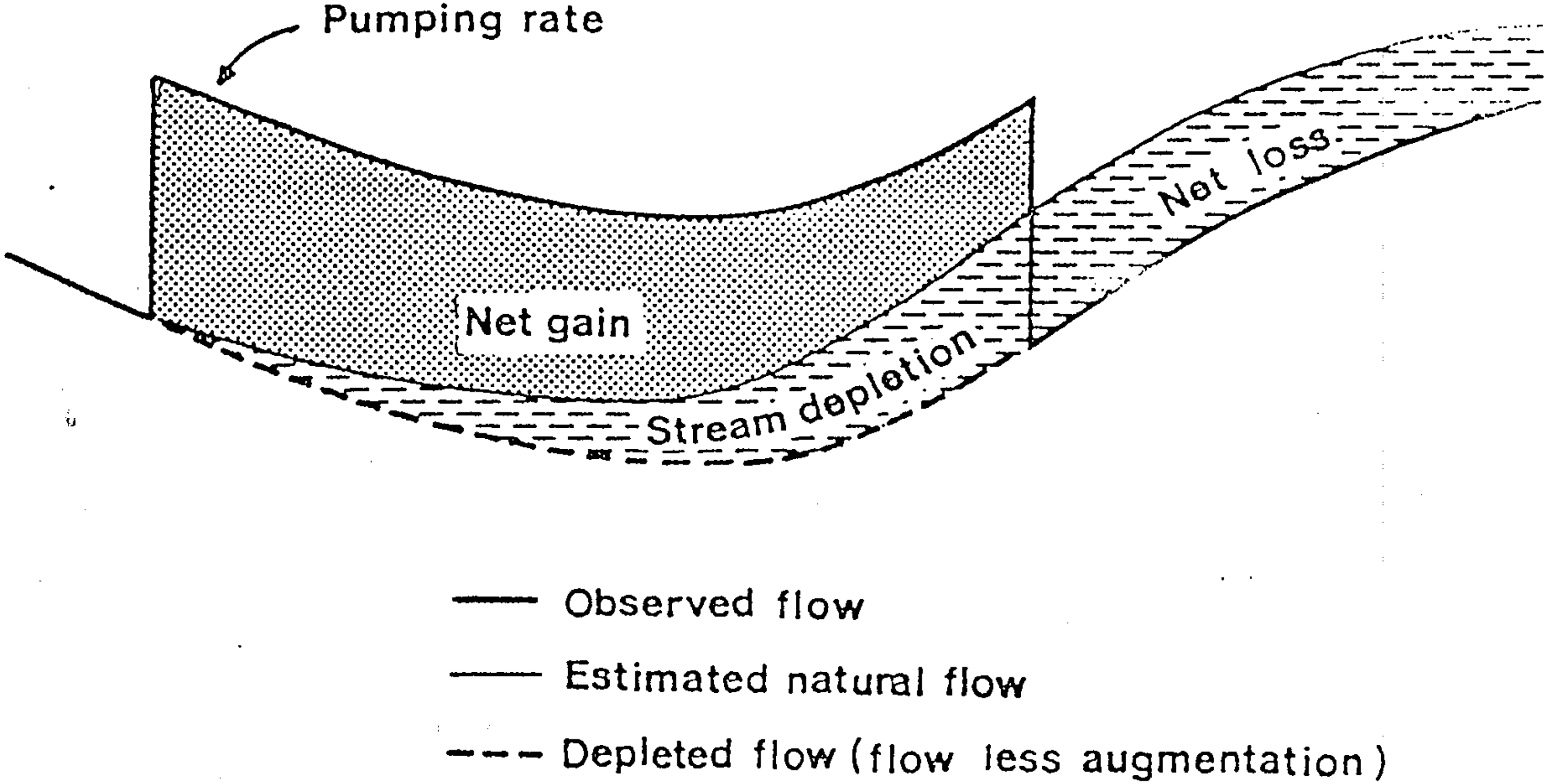

Figure 3 Schematic explanation of net gain and stream depletion.

North West Water

LAKE DISTRICT & LCUS WATER RESOURCES

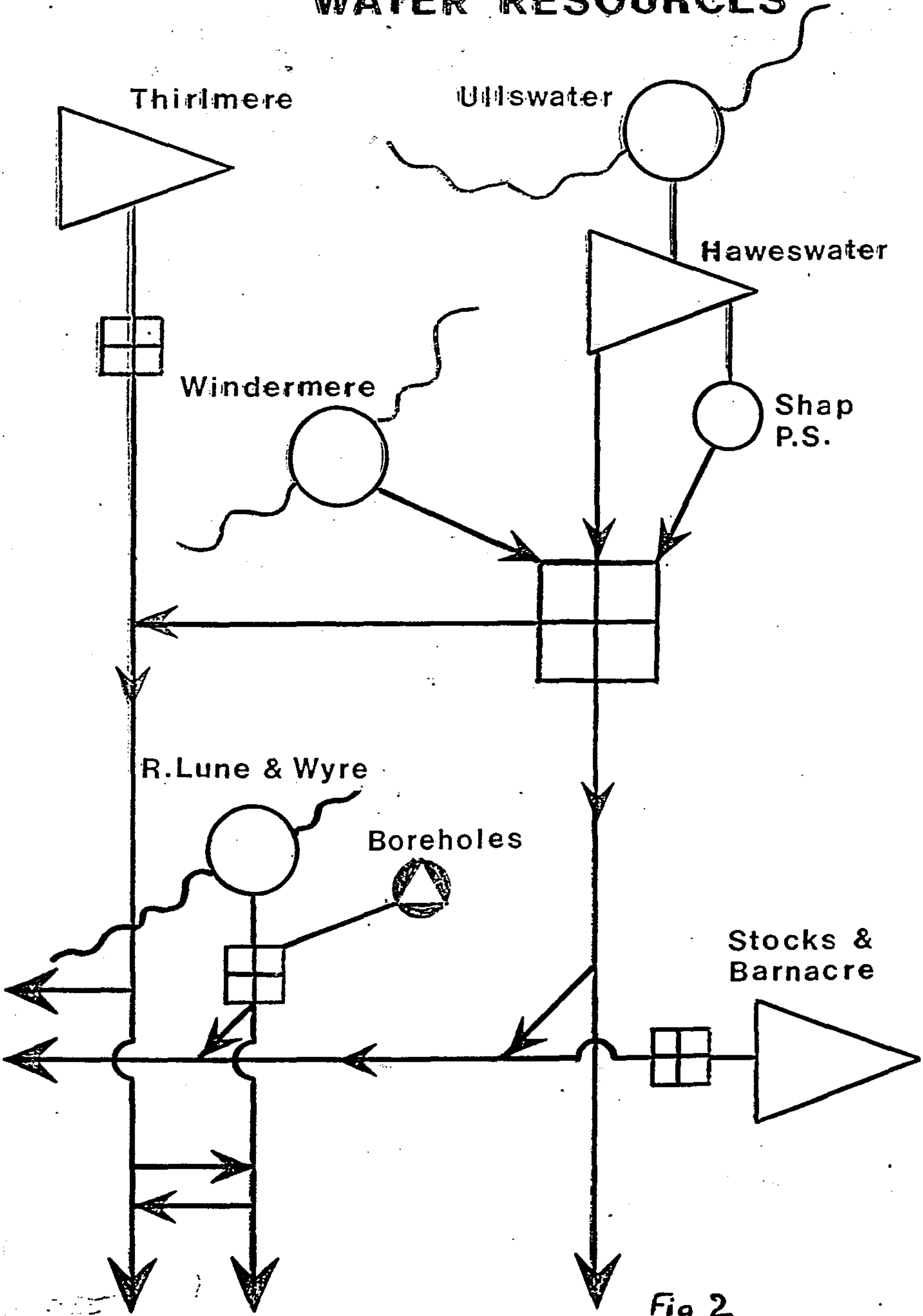

Fig 2

APPENDIX I

NRA - NW REGIONAL FLOOD WARNING SCHEME

Historically, people have built close to rivers so that they could use the water for drinking, irrigation, transportation and a host of other reasons where water is required. However, in seeking these advantages the natural flood plains of rivers and tidal waters have been built upon with the inevitable results that, on the occasions when heavy rainfall or abnormally high tides occur, flooding of property take place.

For many years now, as the pattern of transportation and water supply has developed and changed, there has not been the same need to build near rivers and the National Rivers Authority actively discourages development on such plains. In spite of this, new building still takes place and adds to the problems that have been inherited.

The National Rivers Authority has the power to spend public money on alleviating flooding by improving rivers channels, constructing flood banks, building pumping stations and other works where it is economically viable to do so. Flooding can only be alleviated however, it can never be eliminated. Sooner or later; property on a flood plain will flood.

Given that flooding is inevitable, it is important to provide flood warnings to property owners and to industry so that steps can be taken to reduce the damage that is caused by flooding. Flooding can occur both from rivers in spate and from abnormally high tides.

In order to forecast which rivers are likely to flood, the NRA-NW monitors flows at measuring stations which are built at strategic points on rivers. It also monitors rainfall by raingauges and a weather radar installation which observes and records rainfall for the whole of the Authority area (see fig. 1). All of this equipment transmits information by radio, at 15 minute intervals, 24 hours a day, 365 days a year, to a central computer at Franklaw in central Lancashire. The information on the Franklaw computers is copied to a computer at Warrington. The computers analyse and store the data, and generate alarms when set water levels are exceeded. These alarms, together with heavy rainfall warnings from the Meteorological

Office, alert Regional Flood Warning Duty Officers who use the computers to make more precise forecasts of when and where flooding might occur and then issue flood warnings to the Police.

The use of weather radar as an aid to flood warning has increased substantially since the North West Weather Radar was commissioned in 1979. This project was funded by a consortium comprising the Meteorological Office, North West Water Authority, Water Research Centre, Central Water Planning Unit and the Ministry of Agriculture, Fisheries and Food. The Radar was the first unmanned set in the U.K. specifically designed to monitor rainfall intensity and was the prototype for pioneering work by the North West Water Authority and the Meteorological Office in the development of unmanned weather radar installations and in the use of radar for flood warning (Ref. 1). An additional 13 radars - all based on the work carried out on the North West Radar - will eventually (early 1990's) be built by the Meteorological Office in conjunction with other Authorities, to form the UK National Weather Radar Network.

Tidal flooding occurs on the west coast of England and Wales when normal high tides are enhanced by a combination of depressions in the North Atlantic and westerly gales across the Irish Sea. Computers at the Meteorological Office at Bracknell help in forecasting these conditions. Each day, at about 5 a.m., a message comes through to the forecasting room at Warrington giving details of the effect that weather conditions will have on tidal levels for the next 30 hours. When there is any possibility of flooding, Duty Officers come to the forecasting room and tidal gauges along the Authority's coastline are continually monitored so that the computer forecasts can be adjusted and updated.

When duty officers forecast that flooding might occur, County Police are warned who, in turn, warn Local Authorities. Police also get in touch with householders, industrialists and farmers in areas that might be affected and are also able to call on the very substantial resources of County Emergency and Social Services to handle the many problems that arise during flooding. Information flow is shown in fig. 2.

When early warnings of flooding can be issued the risk of people drowning is substantially reduced and a good deal of damage can be avoided by removing goods and livestock to safer areas and by protecting property with temporary measures such as sandbagging. Police are also able to divert traffic around areas which might flood.

Flood Warning is one of the lesser known aspects of the National Rivers Authority's service to the community, a service which is of great value to people living and working in areas which are liable to flood.

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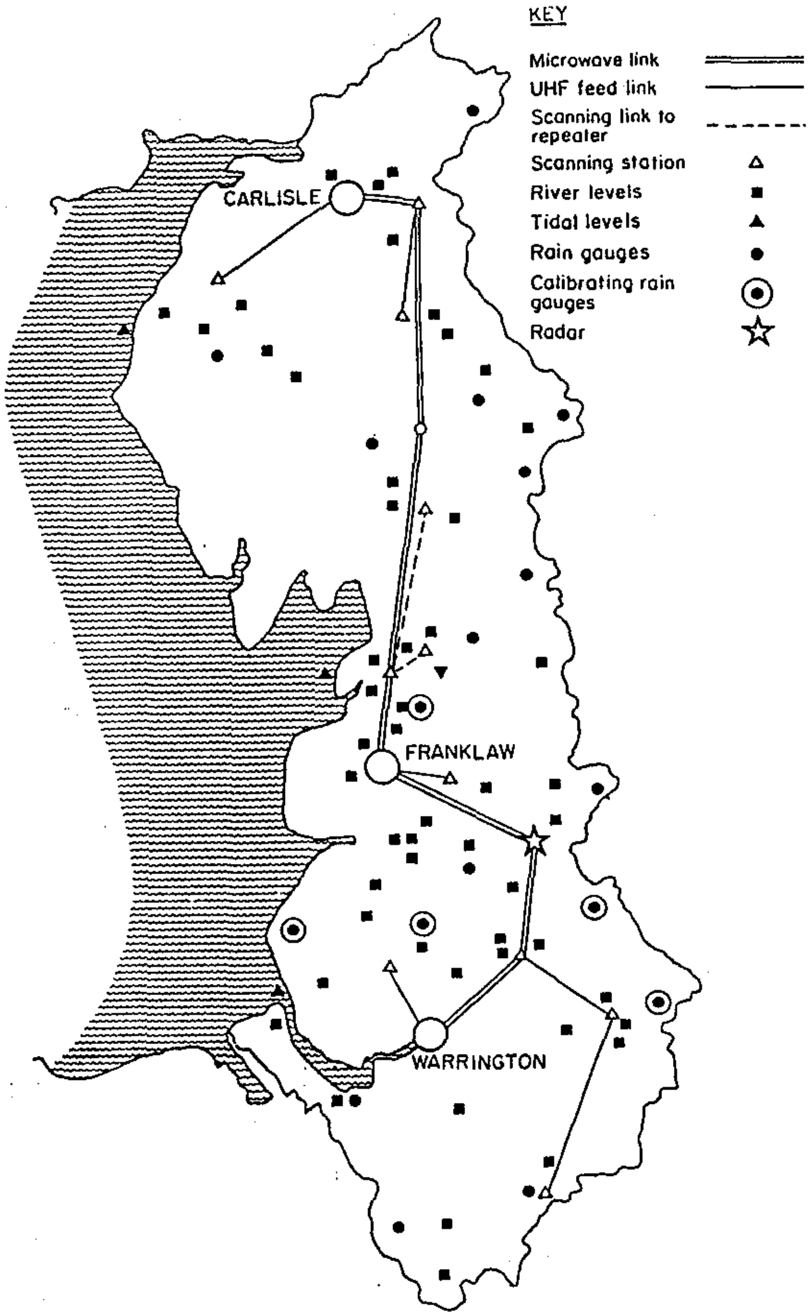


Figure 1. North-West Water communications system

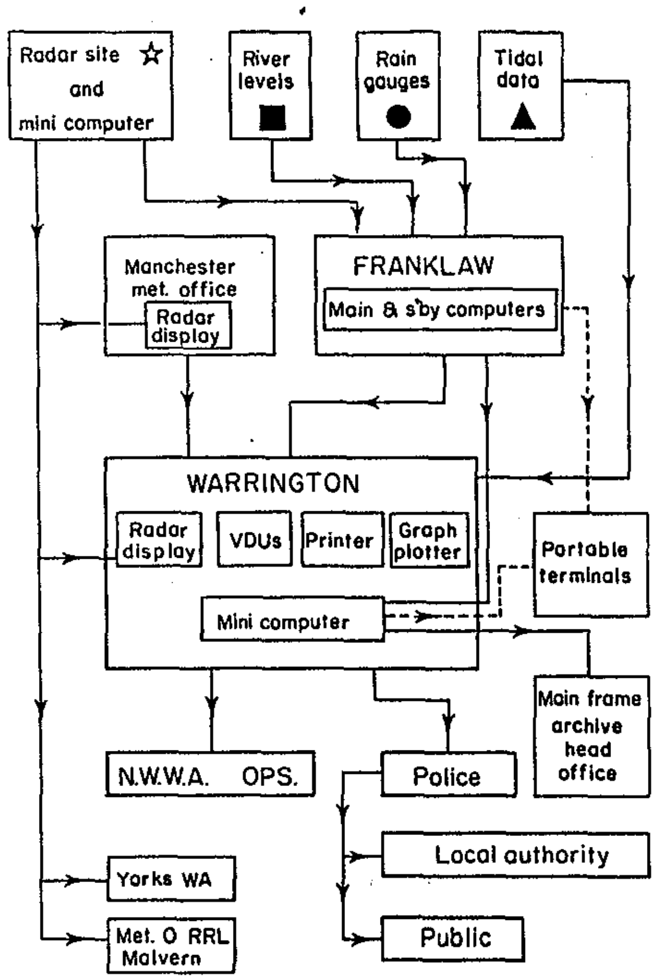


Figure 2. Flow diagram for data and forecast information

"CLIMATIC EXTREMES AND THEIR IMPACT ON LOCAL AUTHORITIES"

Tom Fitzpatrick, Westmeath Co. Council.

1. INTRODUCTION:

Over the past number of years there has been considerable exposure of the effects of major climatic events such as flooding and storm damage. The local television correspondent and his increasingly mobile TV crew have contributed greatly to the transmission of pictures from affected areas into the nation's living rooms. It is thus to be expected that storms and floods create a more vivid and lasting impression on the public than ever before. Indeed, though such climatic events occur on a statistical basis the public may well have the impression that such events are occurring more frequently than heretofore.

Mr. Callery has dealt with the effects of the recent storms with particular emphasis on damage caused to piers, harbours, sea water defences and coastal dune systems. I will outline briefly the effects of recent climatic events on other Local Authority functional areas.

2. HEAVY RAINFALL:

2.1 Flooding:

Over the past winter there has been a number of particularly serious floods caused by heavy rainfall. I will refer specifically to a few random counties which should give a representative, even if narrowly based, view of the impact of last winter's floods.
In Co. Mayo there was serious flooding in Ballina, Westport and Crossmolina in October/November 1989. In the floods of February last Westport was again affected, as were extensive rural areas including part of the National Secondary route between Balla and Claremorris.

I understand that flood alleviation proposals are being submitted to the Dept. of the Environment for Westport and that the Office of Public Works are doing an in depth study of the river associated with the Ballina floods.

In Co. Laois there was extensive flooding in Mountmellick, Portlaoise and Portarlington. Mountmellick was worst affected with floods occurring downstream of the confluence of two rivers.

In Co. Westmeath there was extensive flooding of land downstream of Athlone, which resulted in around 35 houses being isolated by floods. the local Civil Defence were actively involved in transporting supplies to isolated houses.Throughout the operation there was an emphasis on SELF HELP. Four families had to be evacuated. Westmeath County Council provided short term land for stock affected by the floods.

Major flooding also occurred in 1986, most notably in Bray and other areas of Co. Wicklow and Tralee. In Tralee, flooding was caused in 1973, 1975 and 1986 due to heavy and prolonged rainfall. There are two rivers flowing beneath the town. The flooding is being alleviated by the partial diversion of one of these rivers.

2.2 Bridge Damage:

A seminar was arranged by an Foras Forbartha in June 1987 to discuss the causes, consequences and remedial measures associated with bridge collapse.

The seminar focused particularly on the damage caused to bridges in various counties by storms between June and August 1986 and in particular on the full or partial collapse of ten bridges in Co. Wicklow caused by an offshoot depression from Hurricane Charlie on 25th August, 1986.

Over a 24 hour period on 25th August, 1986 between 75mm and 100mm of rain were recorded over large areas of Co. Dublin and Wicklow. The 24 hour rainfall at Kilcoole, Co. Wicklow was 200mm.

Almost all bridge failures were due to scour action. Scour occurred upstream and downstream under both masonry and concrete piers and abutments.

Most failed masonry bridge foundations were carried down to only about 300m below the river bed. Following the storms there was evidence of river bed levels being lowered by up to 600mm by scour.

The seminar concludes that the provision of concrete paving to piers and abutments of masonry bridges would greatly increase their resistance to scouring action. However particular attention should be paid to the design, layout and extent of the concrete paving protection.

2.3 Flood Warning Systems:

2.3.1 The O.P.W. have developed a flood warning system for Kilkenny as described in Mr. Shine's paper. There is also a flood warning system operated on the River blackwater which was introduced following the serious floods in Mallow, and Fermoy in November 1980.

This system has the facility to provide an advance warning of a flood system developing by dialling up to 5 phone numbers when an alarm level is reached.

The system operates based on the historical association between critical river levels at upstream monitoring outstations and actual flood levels recorded downstream of these outstations.

The flood warning system consists of 3 stages .

Stage 1:	Green:	Minor flooding.
Stage 2:	Amber:	Moderate flooding and River has exceeded bank level.
Stage 3:	Red:	Major flooding.

2.3.2 An example of UK experience:

Most warning systems in the UK operate on a correlation basis, where upstream river levels during a flood are correlated with resultant downstream levels for use in future flood levels. Such a system is described above on the River Blackwater.

This system will only give an adequate warning time if the propagation of the flood wave down the river is fairly slow. Since the River Tyne is too steep for the correlation to be effective a system has been installed to predict the run off from the actual rainfall over the catchment.

The system is operated by a PC at a Base station which is in radio contact wwith three outstations, each of which contains a rain gauge. The base station is located at a location which is hard wired to the adjacent river level monitor.

Signals are transmitted from the Base station/River Gauge station to the monitor station, which is a 24 hour manned Police station.

The Rain gauges consist of tipping bucket rain gauges connected to a microprocessor driven data store.

A Hydrological Model linking rainfall and run off was prepared by the Institution of Hydrology.

The flood run off is very much a function of the extent to which the catchment is saturated i.e. the soil moisture deficit at 75mm depth. Since it is almost impossible to obtain real time estimates of the soil moisture deficit, the model uses the discharge from the catchment as an indicator of its saturated condition.

The cost of the hardware associated with this system was ST£18,000 at 1980 prices.

3. *DAMAGE DUE TO PROLONGED DRY WEATHER:*

The most memorable droughts of recent times were those in 1975, 1976, 1983, 1984 and to a lesser extent 1989.

3.1 Damage to Bog Roads:

At the end of last year's particularly fine summer, there was evidence of considerable subsidence and distortion on many County roads throughout the County. In Co. Westmeath this manifested itself as longitudinal cracking. This subsidence was caused by the large drop in water table level as a result of the dry spell.

As a result, in Co. Westmeath roads which had only recently been strengthened, had to be prematurely repaired. Similar experiences have also been reported in other counties having significant lengths of bog roads.

3.2 Water Shortages/Droughts:

Despite the very fine weather during the summer of 1989 the incidence of water shortages throughout the country did not appear to be unduly high.

In his paper to this seminar in 1988, Mr. P. Callery presented ground water as a percentage of total abstraction for all Irish counties. I have carried out a random check on how those counties most dependent on ground water faired throughout last summer.

In Co. Roscommon, which is a dependant on ground water for circa 85% of its total supply, there were problems in one scheme, which required rationing from midnight and 8a.m.

In Co. Westmeath two water supplies required rationing - one for 6 weeks, for between 6-10 hours/night and another for one month for between 3-4 hours/night.

In most counties where problems occurred, these usually involved the drying up of surface water, whether river or impoundment sources. In most counties droughts occurred to a greater extent in 1983 and 1984 than in 1989. Perhaps this is because the relatively wet years between 1984 and 1989 replenished the water table before 1989.

3.3 Reduced Available Dilution for effluent Proposal:

The practice in relation to low flows is to use the low flow which is equalled or exceeded at least 95% of the time.

The requirements of Memorandum No. 1 on Water Quality Guidelines dictate that the BOD of receiving water should not increase by more than 1mg/l and should not rise above 4mg/l as a result of any discharge of effluents.

(a) Thus any decrease in river flow below certain preset levels will result in a poorer quality receiving water downstream of any sewage treatment works and will render receiving waters more vulnerable to accidental spillages such as agricultural pollution.

(b) It is also to be noted that the higher summer temperatures which usually accompany low river flows will result in higher water temperatures and thus lower Saturation Dissolved Oxygen levels. Higher temperatures are usually also associated with higher light intensities and consequently increased plant growth and increased oxygen consumption as part of the respiration/transpiration cycle.

(c) The combination of low river flows coinciding with silage cutting and its consequent agricultural pollution during 1987 resulted in the large number of fish kills that year.

3.4 An increase in the level of Eutrophication:

The standard relationship used to model the behaviour of lakes in response to nutrient phosphorous loads is shown in Figure 1.

The term T(w) is related to the time required to flush out a lake i.e. V/Q where V = Lake Volume (m3)
Q = Annual flow (m3/yr)

Any increase in T(w) will produce a consequent increase in the tendency for the lake to become eutrophic, provided the phosphorus loads to the lake remain constant.

Note:
(The phosphorus loads, if predominantly originating from point sources such as town sewage plants, will most likely remain constant. However if the phosphorus loads originate from different agricultural sources there may be a balance between reduced rainfall/runoff and reduced phosphorus inputs.)

4. *THE FUTURE:*

4.1 The recent ERU publication titled "A Statistical Analysis of River Flows - The Eastern Water Resource Region" has shown no noticeable decreasing trend in low flows in Ireland.

4.2 I would refer to Mr. Sweeney's paper yesterday and its tentative conclusions as a result of the doubling of CO_2 levels before the year 2050.

4.2.1 Increased Variability in Precipitation:

Mr. Sweeney has stated that increased variabiality may characterise Irish precipitation.

For small scale schemes the rational method of design may not be as applicable as it is now, similarly rainfall patterns recently used to characterise storms for certain areas will need to be calibrated based on historical and projected further changes not later than the year 2000 (See Figure 2).

Indeed one of the basis of the Flood Studies Report (i.e. that the probability of occurence of a storm is based on a longterm series of Annual Maxima) may be erroneous if future Annual Maxima are higher than those currently prediced under the F.S.R.

As stated in Mr. Sweeney's paper, a modest increase in rainfall of standard deviation from the mean could provide a decrease in the Return Period of a storm from 1 in 100 years to 1 in 10 years.

Thus the economic benefit of flood relief projects would significantly increase relative to their costs.

Higher rainfall intensities would also lead to an increased frequency of storm overflows in combined sewers, with a consequent decline in receiving water quality.

4.2.2 Possible Variation in Yield/Storage relationships of Water Sources:

The yield of many surface water sources has been calculated using the Lapworth and Bimmic Formula.

$$S = \frac{15\ U^2}{M^{1.85}}$$

S = Storage expressed as inches over whole catchment.
U = Annual Yield expressed as inches over whole catchment.
M = Average Annual run-off expressed as inches (rainfall less evapotranspiration).

It is quite probable that as a result of increases in both rainfall and evapotranspiration, the value for M may remain constant. However in the long term it would be prudent to assess the yields of all sources in say twenty years time based on revised figures for M or indeed on a historical record of inflows and outflows to and from impoundments. (Refer to Figure 3)

4.2.3 Increased Soil Moisture Deficits:

Mr. Sweeney has intimated that as a result of warmer and slightly wetter summers there may be an increasing tendency for soil moisture deficits during the summer.

This may lead to a demand for water for irrigation purposes. Indeed last year, in the Dublin region, there was a rainfall rate of 555mm as against an evapotranspiration rate of 664mm, which indicates that irrigation was theoretically needed last year in this region.

In England there was an increase in the aea of spray irrigated land from 75,000 acres in 1955 to a projected 400,000 acres in 1982.

A National Water Council working group ccepted in 1981 that there could be a 2 to 3 fold increase in water demand for irrigation.

In this scenario there would thus be a requirement for an increased design water supply provision in respect of crops, particularly in the east and south-east of the country.

5. *CONCLUSION:*

Many of the points referred to above may be regarded as highly speculative. However they should be regarded mainly as pointers to further determine the future impact of climatic changes on water resources in Ireland.

The complexity of predicting complete effects of climatic change may well be summarised by a quotation from Lorenz, a meteorologist and one of the initiators of the new science of chaos: "Predictability: Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?".

Figure 8.4

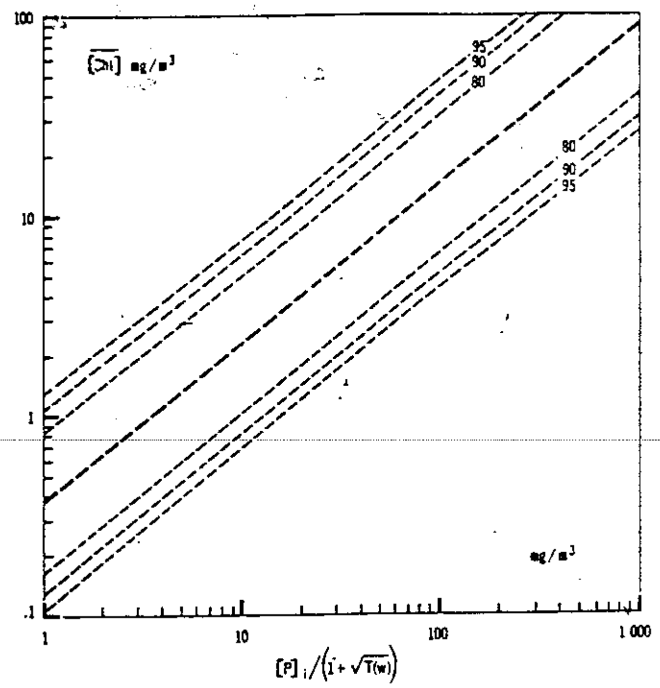


Figure 8.5

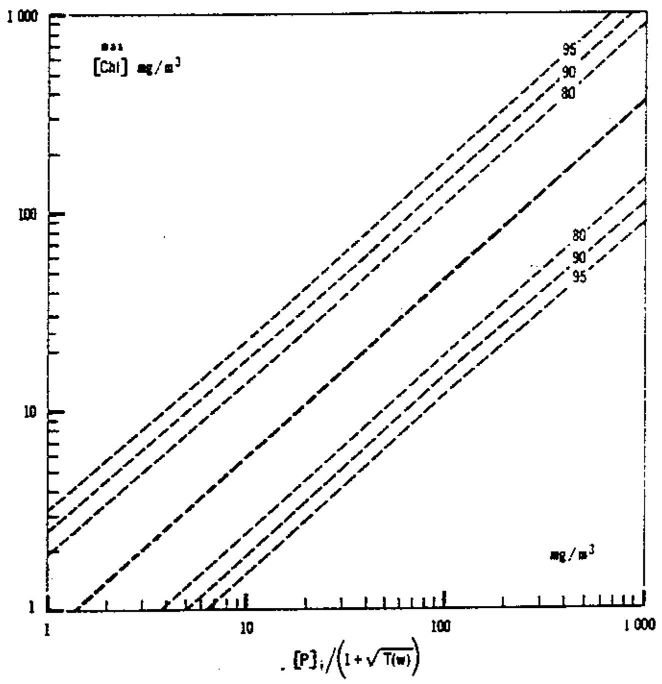


FIGURE 1.

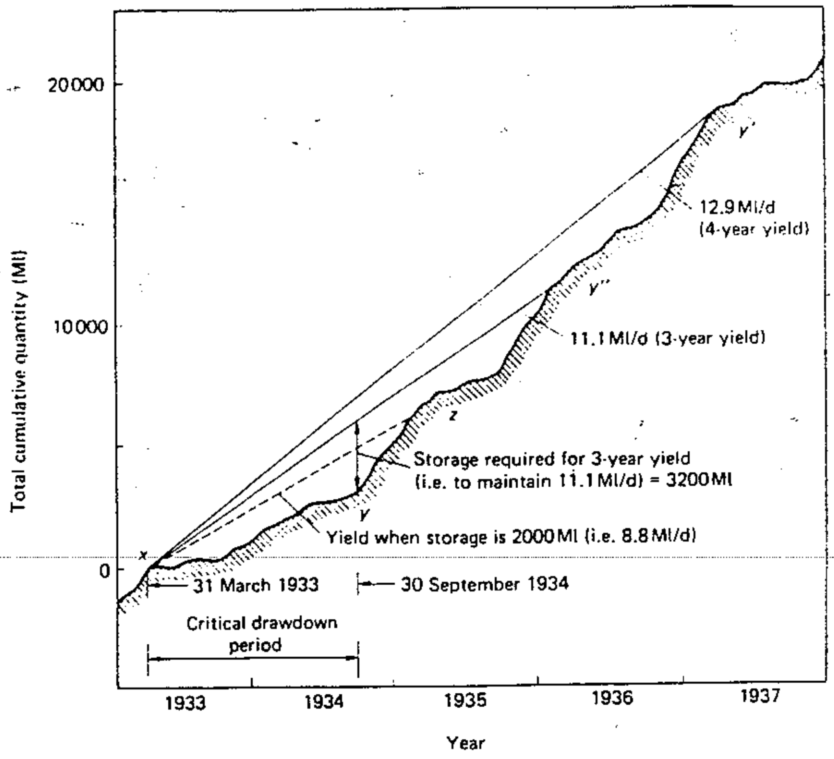
Relationship between Average Influent Phosphorus concentration [Pi], lake flushing time T(w) and predicted chlorophyll a level.

Athlone Area

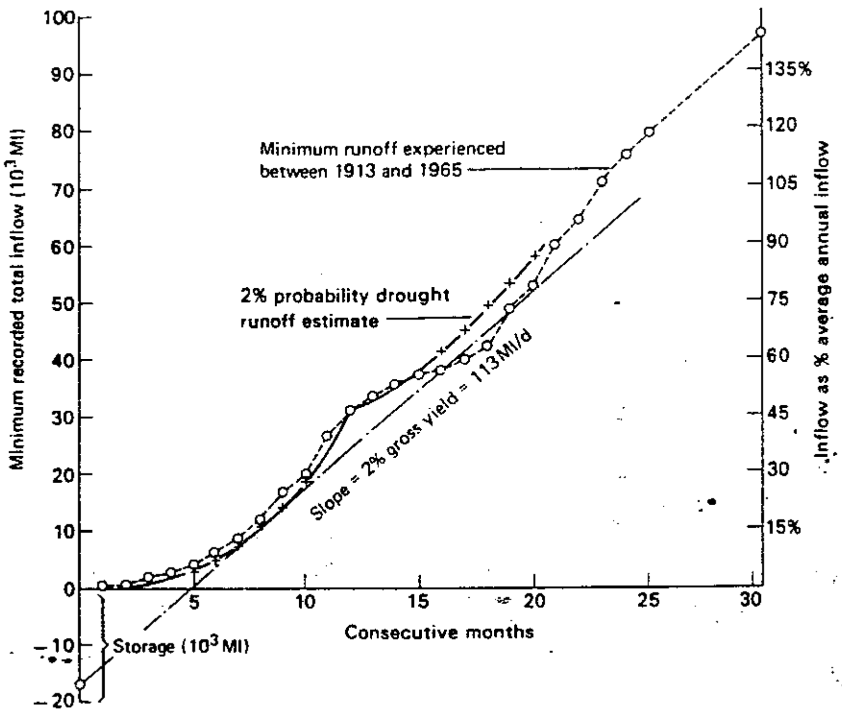
Duration	1 yr.	2 yrs.	5 yrs.	10 yrs.	20 yrs.	50 yrs.
	Return period					
2 mins	2.0	2.2	3.0	3.6	4.4	5.5
5 mins	3.7	4.1	5.6	6.7	8.0	10.1
10 mins	5.3	5.9	8.0	9.6	11.5	14.5
15 mins	6	7	10	12	15	19
30 mins	8	9	13	16	19	24
1 hour	11	12	16	19	23	29
2 hour	14	15	20	24	28	35
4 hour	18	20	26	30	35	42
6 hour	21	23	30	35	40	48
12 hour	27	29	37	43	49	59
24 hour	32	35	44	51	58	70

FIGURE 2.

Estimated Rainfall amounts for specified duration and return period in Athlone.



5-year mass-flow diagram.



Minimum runoff diagram.

FIGURE 3.

Methods of predicting Storage/Yield relationship.

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