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INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH GROUP)

9th ANNUAL SEMINAR, PORTLAOISE, 25th, 26th APRIL, 1989

GROUNDWATER CHEMISTRY AND GROUNDWATER FOR THE BOTTLED WATER AND AQUACULTURE INDUSTRIES

PROGRAMME

TUESDAY 25th APRIL

10.15	Registration & Tea/Coffee	
10.45	Welcome and Introduction	Bob Aldwell (President IAH Irish Group)

Groundwater Chemistry, Monitoring and Protection

11.00	Natural chemistry of groundwater	Eugene Daly (G.S.I.)
11.35	Variations in groundwater quality	Richard Thorn (Sligo R.T.C.)
11.50	Groundwater monitoring	Catherine Coxon (T.C.D.)
12.10	Approaches to aquifer protection	Donal Daly (G.S.I.)
12.40	Discussion	
13.00	Lunch	

Bottled Waters

14.15	Standards and certification for bottled waters	Richard Foley (EOLAS)
14.50	The bottled water boom	Timothy Green (Co-author of *The Good Water Guide*)
15.30	Tea/Coffee	
15.50	Geology and chemistry of various bottled waters	Peter Bennett, Stephen Peel & Eugene Daly
16.30	Bottled water - the Irish experience	Brian Duffy (Glenpatrick) Geoff Read (Ballygowan)

Wednesday 26th April

09.30	Water quality for farmed salmonids	Gerard Morgan (U.C.C.)
10.05	A discussion of groundwater sources for fish farming	Kevin Cullen (Consultant Hydrogeologist)
10.40	Tea/Coffee	
11.10	Fish farming in Ireland - An overview	Pat Timpson (Sligo R.T.C./ fish farmer)
11.45	The business of aquaculture	Liam Kielthy (National Development Corporation)
12.20	Discussion and close	
12.45	Lunch	

NATURAL CHEMISTRY OF GROUNDWATER

(This is the text of a lecture to be given at the I.A.H. meeting in Portlaoise in April, 1989. Tables and Figures will be included in the lecture).

Eugene P. Daly - Geological Survey

1. Introduction

In Ireland the consolidated (bedrock) geological succession covers a large part of geological time as we know it, from the Precambrian rocks at Rosslare (SE) and Erris (NW) to the basalts and Lough Neagh clays of Tertiary age in the northeast. A variable thickness (up to 60m) of the most recent deposits of Quaternary age (unconsolidated) covers much of the island.

The most important water bearing strata (aquifers*) are some of the limestone ($CaCo_3$) and dolomite ($CaMg(CO_3)_2$) formations (Lower Carboniferous) and the sand and gravel deposits (Quaternary) which are found and have been developed throughout Ireland (Table I). Some minor aquifers, such as the sandstones in the northeast (Permo-Trias) and the south and midlands (Kiltorcan - Devonian/ Carboniferous), are very important in certain regions. A summary of the geology, hydrogeology and resources of these aquifers is contained in a report and set of maps published by the European Commission (referenced at back). Kevin Cullen will develop this topic further in his lecture.

In this lecture it is intended to provide the background hydrogeological and hydrogeochemical information necessary for the subsequent contributions in order that they may be seen in the overall context.

2. Hydrologic Cycle

Water movement on this planet can be described in simple terms by the hydrologic cycle. Here we are interested in the underground part of that cycle i.e. the flow of water from the point where it infiltrates below the land surface (recharge area) to the point where it discharges to springs/ streams/rivers or directly to the sea (discharge areas) and to all points in between.

* An aquifer is defined as a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients. In Ireland this essentially means strata that will normally yield supplies of at least 250 m^2/d to wells over most of their area.
An aquitard is a saturated geological unit of low permeability which permits some groundwater flow at very slow transmission rates.
The upper surface of the saturated zone is called the water table.

Over the recharge areas of the aquifers in Ireland, approximately 0.2-0.9 of the potential recharge (350-750mm/yr) moves underground. Toth's model (1963) can be used to describe groundwater flow in most field areas. He visualizes water moving within a series of cells at different levels.

(a) Local System of Groundwater Flow.

Here groundwater is moving at shallow depths normally relatively quickly and along short flow path to the discharge points. Most groundwater flow (e.g. all flow in sand and gravel and karst aquifers) in Ireland can be considered to take place at this level i.e. say within 100m of the water table. Most development has taken place in this part of the groundwater regime.

(b) Intermediate System of Groundwater Flow.

In Ireland flow at this level (say 100-500m) is confined(+) and will be at relatively slow flow rates owing to the reduction in permeability, the absence of a significant hydraulic drive and the presence of structural/ lithological barriers to flow. What flow there is, probably takes place along faults. The deeper flow in the dolomite and sandstone aquifers would be typical of this system about which we have very little hydrogeological or hydrochemical information in Ireland.

(c) Regional System of Groundwater Flow.

If any flow occurs at this level in Ireland it would be extremely slow, in very small quantities and be following long and complicated flow paths. With our present state of knowledge one can only hazard a guess about possible discharge mechanisms.

3. Chemical Evolution of Groundwater

The chemistry of precipitation (a dilute, slightly to moderately acidic, oxidizing solution) is altered significantly as it passes through the thin and biologically active soil zone. As this infiltrated water moves along flow paths from recharge to discharge areas its chemistry is altered by a number of hydrochemical processes which continuously try to achieve equilibrium between the water and the strata with which it is in contact. Obviously factors such as the rate of groundwater flow, the dissolving properties of the water, the minerals present (and their solubility) and the geological environment through which the water is passing will have an important effect on the resulting groundwater chemistry.

(+) A confined aquifer is one that is confined between two aquitards. An unconfined (or water table) aquifer is one in which the water table forms the upper boundary.

As rainfall containing dissolved O_2 and CO_2 enters the soil it sets up a number of reactions which generate acids e.g.

$$O_2(g) + CH_2O \text{ (oxidation)} \rightarrow CO_2(g) + H_2O \rightarrow H_2CO_3 \text{ (carbonic acid)}$$

Carbonic acid is the most important species in the dissolution of minerals. Other inorganic and organic acids (humic, fulvic) normally play a minor role. This reaction is kept going by the decay of organic matter and plant respiration which gives a continuous supply of CO_2 and hence carbonic acid.

In a series of acid-base reactions these acids dissolve rock minerals (e.g. calcite and dolomite) and transport them to the water table and the groundwater flow system. In water, minerals dissociate into cations (+) and anions (-) e.g.

$$CaCO_3 \text{ (calcite)} + H_2CO_3 \rightarrow Ca^{2+} + 2\ HCO_3^-$$

As water moves through the groundwater system it becomes involved in a number of hydrochemical processes such as solution, ion-exchange, redox reactions, diffusion, mixing, etc., which alter its chemistry. These processes and the resultant water types (facies) tend to evolve along certain sequences which are described below.

Further information on these processes and the topic in general can be found in the textbooks by Freeze and Cherry (1979) and Lloyd and Heathcote (1985) referenced in Section 10.

4. Hydrochemical Sequences.

(a) Anion Evolution.

In aquifers throughout the world it has generally been found that there is a gradual increase in the concentration of the major ions (and hence total dissolved solids (TDS)) as water moves from the recharge areas to deeper parts of the same system and then to the discharge area. Scientists working in Australia and Russia in the 1950's found that water tends to evolve chemically towards the composition of seawater. This process is accompanied by regional changes in the dominant anion species in the following sequence:

$$HCO_3^- \rightarrow HCO_3^- + SO_4^{2-} \rightarrow SO_4^{2-} + HCO_3^- \rightarrow SO_4^{2-} + Cl^- \rightarrow Cl^- + SO_4^{2-} \rightarrow Cl$$

$\longrightarrow$

Travel along flow path.

Generally increasing age (or residence time in the aquifer).

Reduction in redox potential (oxygen depletion).

is progressively lowered a series of reduction reactions take place and the groundwater environment becomes more and more reduced.

In the reaction described earlier where organic matter is oxidized the Eh is lowered to the point where nitrate (and MnO_2 if present) are reduced. The sequence continues with the reduction of ferric iron minerals then the reduction of sulphate to H_2S and if sufficiently negative potentials are reached then the remaining organic matter will be converted to methane (CH_4) and CO_2.

Most of these reactions are biologically catalysed. The sequence of redox reactions is paralleled by an ecological succession of micro-organisms with various bacterial species adapted to the different stages of the redox sequences. In the absence of oxygen at deeper levels (or distance from the recharge area) anerobic conditions may prevail.

The solubility of dissolved oxygen in water is low ($\simeq$11mg/l at 10°C). In subsurface environments O_2 replenishment is limited (especially in confined environments where groundwater is isolated from the atmosphere). A small amount of organic matter oxidation can result in the consumption of all the dissolved oxygen. The consumption of dissolved oxygen above the water table in recharge areas is dependent on numerous factors. From the small number of studies of dissolved oxygen in groundwater it appears that dissolved oxygen can move into the groundwater system at detectable levels in recharge areas with thin or light soils overlying permeable fractured rocks and not in areas with thick heavy soils (high organic matter content). In the absence of dissolved oxygen, carbon dioxide (and hence H_2CO_3) can be produced by the oxidation of organic matter by nitrate and sulphate.

As in the case of the anion evolution sequence the electrochemical sequence does not always evolve to the end stage (i.e. low Eh and production of H_2S and CH_4). This may be due to the absence of sufficient organic matter or the inability of the necessary redox bacteria to thrive in the particular environment.

Both the anion and electrochemical evolution sequence when combined with other hydrochemical analysis and hydrogeological data can provide considerable information on the flow in aquifer systems.

Our present knowledge (although quite limited) of groundwater flow in Ireland suggests that most of the flow is relatively quick and of limited duration underground. Nevertheless many of the reactions and processes described above have been encountered in various studies. Examples will be given in the course of the lecture at Portlaoise.

presence of sodium bicarbonate, the onset of a change to this type of water and generally a slowdown in the rate of groundwater movement. This occurs via the process of natural ion-exchange whereby sodium replaces calcium and magnesium. In the bedrock aquifers the source of sodium is the clay deposited during their marine deposition whereas in the sand and gravel aquifers it is mainly clay minerals produced by glacial erosion and present in small quantities in this type of aquifer. Two examples in the Nore River Basin illustrate this process i.e. in the Castlecomer Plateau (Westphalian Sandstone) where the process is complete and in the Kilmanagh River Gravels (where the process occurs in both the Quaternary aquifer and the underlying limestones) where it is only partially complete.

In the northeastern part of the country where evaporite lenses (mainly gypsum) are found frequently throughout the limestone sequence both shallow and deep waters show evidence of the reduction of sulphate to H_2S and the production of methane.

In the early 1960's two oil exploration boreholes drilled by Ambassador Irish Oil encountered water with significant concentrations of sodium chloride. One of the boreholes hit fresh water between two layers of brackish water (one at 117m and the other at 652m). In the Permian and Triassic sandstones in County Antrim deep boreholes have yielded brines at depths in excess of 1000m.

In the 1980's investigations into the warm and tepid springs (i.e. 11°-25°) were carried out initially on a national basis and then in the four areas where most of the warm springs occur. In all but one area (the Celbridge Syncline) the water chemistry is typical of normal limestone waters and indicates a short residence time in the aquifer. These warm springs probably result from the mixing of small amounts of quite warm water with large amounts of cold shallow groundwater which mask the true chemistry of the warm waters and which have come to the surface at specific points along large, deep faults. Two of the springs in the Celbridge Syncline are slightly brackish (TDS $>$ 1,000 mg/l) sodium chloride waters with significant calcium bicarbonate. Obviously a significant part of these waters has been in circulation for a long time and at some depth.

6. Age of Groundwaters in Ireland

There has been very little age dating of Irish groundwaters. Some useful information has been obtained as part of the geothermal investigations referred to above. The results of environmental isotope and inert gas analysis of samples taken from the warm and cold springs derived from the limestones in North Munster (Bruck et al, 1986) and Central Leinster (Minerex Ltd, 1983) show that most of the waters in both types of spring are modern (less than 25 years) rapidly circulating groundwaters. Most of the groundwater mixture in four of the warm springs in Leinster and one in Munster appear to have a longer residence time and the water in the spring at Louisa Bridge (Celbridge Syncline near Leixlip) is thought to have infiltrated in excess of 10,000 years ago.

Several samples taken in 1970 for environmental isotope analysis in the limestones of the Gort Lowland of South Galway and Northeast Clare showed that the bulk of the groundwater mix was at most less than four years old (Bowen and Williams, 1973).

Carbon 14 analysis of a few samples from artesian boreholes in the Westphalian sandstones of the Castlecomer Plateau gave ^{14}C dates of 1400 years and 5000 years for groundwater 1.0-1.5 km and 8.0 km from the outcrop, respectively.

These results and our knowledge of the flow system suggest that most shallow unconfined groundwaters coming from springs or medium-high yielding boreholes are less than ten years old. However some of the deep confined groundwaters may be up to thousands of years old.

7. The General Character, Potability and Temperature of Irish Groundwaters

There are a reasonably wide range of groundwaters available from the aquifers in Ireland. The waters are normally potable, hard (although softer waters are available in most regions), of good bacteriological quality and suitable for a wide range of uses.

Nitrate concentration has been found to be a reasonably good indicator of human influence on groundwater quality. A general survey of nitrate levels in the major springs (mainly from the unconfined parts of limestone or Quaternary aquifers) throughout the Republic and more detailed studies in the Nore, Barrow and Maine (Co. Kerry) catchments, County Galway and the Northeast and Southeast Regions have shown that normally the nitrate levels in the groundwaters of the Republic are quite low. Nevertheless, medium to high concentrations of nitrate have been found, especially in those areas where the aquifers are unconfined and/or with a thin Quaternary cover, in small areas (individual farms or villages) and in and around urban centres. The point nature of the nitrate sources are illustratred by the frequent occurrence of low and high nitrate levels in close proximity. There is evidence which suggests that nitrate concentrations at deeper levels and in confined aquifers are quite low. The behaviour of other pollution indicators such as ammonia, coliform bacteria, etc., is similar. This topic will be discussed in more detail in other lectures at this session.

Natural concentrations of chloride in groundwater in Ireland are quite variable owing to the geographical location of the island. The distribution of chloride in groundwater is similar to that in rainfall i.e. a general reduction from west to east and away from the coast (Figure III). Values as high as 100 mg/l have been recorded along the west coast. Normal coastal values range from 0-50 mg/l whereas inland they vary from 10-20 mg/l.

Normal groundwaters are rarely analysed for fluorine, silica, carbon dioxide and dissolved oxygen and what values exist are for unconfined groundwaters. Concentrations of fluorine range from 0.02-0.3 mg/l with values up to 0.8 mg/l being recorded. Levels of silica are normally between 2 and 4 mg/l. Concentrations of dissolved oxygen and carbon dioxide generally range from 6-9 mg/l and 10-40 mg/l respectively. Levels of carbon dioxide of 70 mg/l have been recorded.

Aside from the warm springs already mentioned the temperature of groundwaters in the upper 30m is approximately equal to the annual mean daily air temperature i.e. from about 9.0°C in the north to just over 10.5°C along the south coast. One of the remarkable characteristics of groundwater is its almost constant temperature which varies by less than 1°C throughout the year. Geophysical well logs in deep boreholes (up to 500m) tapping mainly confined aquifers show a temperature gradient of 1-3°C/100m. This constant temperature can be a very important and inexpensive tool in certain types of groundwater investigations.

8. Natural Occurring Problem substances in Groundwater

A number of constituents in certain concentrations give rise to problems for some uses of groundwater. The principal ones in Ireland are iron, manganese, chloride, sulphate, hydrogen sulphide and suspended solids. Other features that may cause difficulties are the corrosive and incrusting powers of some groundwaters. Aquifers with some of these problem substances are shown in the EC maps referred to earlier.

Iron concentrations in excess of 0.2 mg/l are frequently found in Irish groundwaters especially in poor aquifers or non-aquifer rocks. Iron in groundwater may be derived from a number of possible sources, for instance the water bearing strata, poorly drained areas or peatlands overlying the aquifer, corrosion of well casing and fittings and the growth of iron bacteria in borholes/wells etc. The iron containing strata are certain sandstones, shales, argillaceous (muddy) limestones, crystalline rocks and

9. Conclusions.

A reasonable variety of fresh and generally good quality groundwaters are available in reasonable quantities throughout Ireland. These waters are suitable for a wide range of uses. Some unusual groundwaters are available at depth or in a few limited areas near the surface.

10. References.

This lecture has been prepared from material contained in a few textbooks and from data collected and reports prepared either entirely or in part by the Geological Survey. The following may be referred to for additional material:

FREEZE, R.A. and CHERRY, J.A. 1979. Groundwater. Prentice-hall Inc., New Jersey.

LLOYD, J.W. and HEATHCOTE, J.A. 1985. Natural inorganic hydrochemistry in relation to groundwater. Clarendon Press, Oxford.

GEOLOGICAL SURVEY, 1982. Groundwater Resources of the Republic of Ireland. For the European Commission. Schafer Druckerei Gmbh, Hannover.

- 1983. Groundwater Vulnerability and Quality in the Republic of Ireland. For the European Commission (in press).

GEOLOGICAL AGE	LITHOLOGY	DISTRIBUTION	IMPORTANCE	REMARKS
Quaternary	Sands and gravels	Widespread	***	Yields up to 2000m³/d. Have been some difficulties in development.
Tertiary	Basalt	NE (Co. Antrim)	*	Little known.
Cretaceous	Chalk	NE (Co. Antrim)	*	Recharge via fissures in the basalts. Very limited outcrop.
Permo-Triassic	Sandstones	Lagan Valley, NW, W, and SW of Lough Neagh. Kingscourt	***	Major source of supply in Belfast area.
Carboniferous Westphalian	Sandstones	Castlecomer Plateau and Slieveardagh Hills	*	Artesian, low recharge
Upper Visean	Clean limestones	Widespread	****	Generally karstified. Numerous large springs. Wide range of well yields.
Visean "Calp"	Sandstones	NW, W, Shannon Regions(+)	**	Well yields as high as 1000m³/d have been recorded.
Tournaisian	"Reef" and dolomitised "reef" limestone	Widespread	***	Well yields of 2000m³/d are common in the south.
Tournaisian	Limestones	NW Region and Co. Armagh	**	Evaporite lenses give high levels of sulphate in places
Tournaisian	Sandstones	NW and E Regions	*	Limited outcrop area.
Devonian (Kiltorcan Form.)	Sandstones	SE, S and Shannon Regions	**	Well yields of 500-1000m³/d obtained regularly. Frequently Artesian.
Ordovician	Tuffs, lavas	SE and E regions	**	Patchy distribution. Well yields of 200-1200m³/d

**** Very important *** Fairly important ** Some importance * Only locally important (+) Water resource regions in Rep.

TABLE I. The Principal Aquifers in Ireland. Their Importance and Distribution.

AQUIFER	TYPICAL GROUNDWATER CHEMISTRY
Sands and gravels	$Ca(Mg)(HCO_3)_2$ waters. Where derived from calcareous rocks the waters are hard (TH 250mg/l) with pH of 7-8. Waters from other strata are softer (TH 150mg/l) with pH of 6-7.
Tertiary basalts*	$Ca(Mg)(HCO_3)_2$ type waters. TH of 200-300mg/l with pH of 7-8.
Chalk*	$Ca(Mg)(HCO_3)_2$ type waters. TH of 250-350mg/l, TDS of 400-500mg/l and pH of 6.5-7.5.
Permo-Triassic* and Sandstones	$Ca(Mg)(HCO_3)_2$ type waters. TDS of 300-400mg/l, TH of 200-300mg/l and pH of 7-8. Manganese sometimes exceeds EC limits.
Westphalian Sandstones	Groundwaters change from $Ca(Mg)(HCO_3)_2$ to $NaHCO_3$ as they move away from the recharge area. Increases in TDS and TA and decrease in TH accompany this change. Fe and/or Mn can be a problem.
Visean Limestones	Hard to very hard groundwaters $Ca(Mg)(HCO_3)_2$. In open karst systems where residence time is short there can be a wide range in hardness throughout the year. TDS of 400-500mg/l. Waters can be incrusting. In discharge areas TH is normally greater than 300mg/l.
"Calp" Sandstone	Similar to limestone waters. Levels of iron frequently excessive.
"Reef"/dolomitised "reef"	Similar to limestones. Where dolomitization is extensive there are increases in magnesium concentration, the Mg/Ca ratio and the TH to 350-400mg/l.
Tournaisian Limestone	Similar to other limestones. However in places the presence of evaporites results in a mixture of $CaSO_4$ and $Ca(Mg)(HCO_3)_2$ waters. SO_4 levels can be up to 1000mg/l and TDS in excess of 2000mg/l. Iron and manganese levels can be high.
Tournaisian Sandstone	Little information. Generally similar to limestone waters.
Devonian Sandstone	$Ca(Mg)(HCO_3)_2$ type waters. The chemistry of the waters are quite variable. TDS of 150-350mg/l, TH of 80-300mg/l and pH of 6-8. The softer, less mineralized and slightly acidic waters are found where the Quaternary deposits are thin or absent and contain little calcareous material.
Ordovician Volcanics	Calcium or mixed bicarbonate waters with TDS and TH generally less than 200mg/l and 150mg/l respectively and pH of 607. Iron can sometimes be a problem.

* P. Bennett, Personal communication.

TABLE II - Typical Groundwater Chemistry of the Principal Aquifers in Ireland.

PARAMETER \ BOREHOLE NUMBER AND LOCATION	WEX 7/1 N.E. of Gorey Wexford	WEX 26/2 S.E. of Enniscorthy Wexford	NC. 4 Skibereen Rd. Waterford	KNY 21/7 Knocktopher Kilkenny	CARRICUG-ARIFF W.S. Waterford	KNY 3/27 Galmoy Kilkenny	KNY 27/53 Kells Kilkenny	CW 16/3 Bagenalstown Carlow	KNY 12/34 Tubbrid Kilkenny	CW 7/14 Cloghrenan Carlow
DATE SAMPLED	Aug '79	Aug '79	June '74	July '80	Oct '78	March '72	July '80	Nov '81	Feb '72	March '81
LABORATORY	I.I.R.S	I.I.R.S.	Mahon + McPhillips	State Lab.	Mahon + McPhillips	State Lab.	State Lab.	State Lab.	State Lab.	State Lab.
pH	6.4	8.1	6.7	7.0	5.2	6.8	7.3	7.35	7.3	8.0
TOTAL DISSOLVED SOLIDS (mg/l)	92	194	150	280	70	390	506		436	464
TOTAL HARDNESS (as $CaCO_3$) "	60	138	117	185	32	366	370	329	368	230
TOTAL ALKALINITY " "	18	120	83	184	16	320	338	286	312	230
CALCIUM "	8.0	25.6	28	54	6	106	110	114	105	64
MAGNESIUM "	9.7	app 18	11.4	12.2	4.1	24.8	22.9	10.7	25.8	17.0
SODIUM "	24	30		16.0			6.6	10.4		10.2
POTASSIUM "	3.1	1.3		1.9			2.5	2.8		0.73
BICARBONATE "	22	146	101	225	20	390	412	349	381	281
CHLORIDE "	35	25	39	20	30	22.0	26	24	24	17
SULPHATE "	app 45.0	app 40		Neg.			Neg.	12		Neg.
Nitrate (as N)	0.47	2.08		2.95	3.0		5.0	6.4	2.0	Nil.
FREE + SALINE AMMONIA " "	< 0.1	0.37		0.01	0.02		0.01	0.017	0.05	0.085
ALBUMINOID AMMONIA " "				0.01			0.01	0.015	0.05	0.085
MANGANESE			0.6	Nil.		Nil.	Nil.	0.06	Nil.	Nil.
IRON "	< 0.1	1.6	0.28	Nil.		0.2	0.03	Nil.	0.16	Nil.
AQUIFER	Ordovician Volcanics			Upper Devonian Sandstone		Dinantian Dolomites			Cullahill Limestone	

TABLE III REPRESENTATIVE CHEMICAL ANALYSES OF SAMPLES FROM THE AQUIFERS IN THE SOUTHEAST REGION

PARAMETER / BOREHOLE NUMBER AND LOCATION	KKY 43/68 Blossom Hill Dunkitt Co.Kilkenny	WEX 42/174 Piercestown Co.Wexford	WEX 47/53 Mayglass Co.Wexford	KKY 1/24 Chatsworth Co.Kilkenny	KKY 2/13 Crutt Co.Kilkenny	TY 55/65 Ballincurry Co.Tipperary	WEX 26/11 Enniscorthy Co.Wexford	KKY 18/93 Oldtown Co.Kilkenny	CW 7/13 Mortarstown Co.Carlow	WEX 47/76 Walshestown Co.Wexford
DATE SAMPLED	July '79	Oct '76	June '78	May '76	May '76	July '78	Feb '80	Aug '79	Jan '81	Sept '76
LABORATORY	An Foras Forbartha	State Lab	State Lab	State Lab	State Lab	State Lab	State Lab	State Lab	State Lab	State Lab
pH	7.3	7.6	7.5	6.7	7.5	7.1	6.80	7.4	7.4	7.5
TOTAL DISSOLVED SOLIDS (mg/1)		352	420	230	353	283	157	336	500	387
TOTAL HARDNESS (as $CaCO_3$) "	284	254	292	169	133	225	110	298	320	293
TOTAL ALKALINITY " "	261	286	285	170	309	237	60	278	304	307
CALCIUM "		37.2	79.4	51.2	32.4	68	20	103	118	82
MAGNESIUM "		39.2	23.0	10.0	12.6	13.4	14.6	9.7	6.3	21
SODIUM "		23.7	26.3	12.5	88.0	18.8	14.0	6.4	12.0	25
POTASSIUM "		2.0	2.1	0.7	5.0	1.3	3.9	1.6	0.64	2.0
BICARBONATE "		349	348	207	377	289	73	339	371	375
CHLORIDE "	22	47	38	18	15	17	25	21	22	41
SULPHATE "		Neg.	12.0	-	-	2.0	26	Neg.	2.0	-
NITRATE (as N) "	2.1	0.88	1.5	0.75	0.25	1.4	5.5	4.2	2.8	0.49
FREE + SALINE AMMONIA (as N) "	0.02	0.10		0.049	0.35	0.04	0.033	0.018	0.035	0.07
ALBUMINOID AMMONIA " "		0.045		0.24	0.17		0.039	0.072	0.01	0.045
MANGANESE "		0.5		1.4	-	0.2	Nil	Nil	Nil	0.11
IRON "		0.5		4.3	0.26	Nil	Neg.	0.08	Nil	Nil
AQUIFER	Southern Limestones	South Wexford Limestones		Westphalian Sandstones			Sands and Gravels			

TABLE III continued.

Table III Analyses of Representative Samples from a Number of Quaternary Deposits Throughout Ireland

Parameter \ Borehole number and location	KNY 18/93 Oldtown, Co. Kilkenny (1)	No. 2 Rosemount, Co. W'Meath (2)	WEX 26/11 Enniscorthy, Co. Wexford (3)	No. 2 Kilcloyne, Co. Cork (4)	Dug Well Geesala Belmullet, Co. Mayo (5)	Co. Co. B/H Drumiskin, Co. Louth (6)	LS 16/58 Camaross, Co. Laois (7)	LS 2/3 Clonaslee, Co. Laois (8)	No. 5 Ardmily Beg, Co. Louth (9)	Glarryford B/H Ballymena, Co. Antrim (10)	Seven Springs Pollardstown, Co. Kildare (11)
Date sampled	Aug. 1979	May 1982	Feb 1980	Oct. 1979	Feb. 1982	Feb. 1982	Nov. 1976	Aug. 1979	Dec. 1982	May 1977	March 1980
Laboratory	State Lab	State Lab	State Lab	HRS	State Lab	State Lab	State Lab	State Lab	HRS	GSNI	State Lab
pH	7.4	7.1	6.80	6.4	6.65	8.1	6.4	7.25	7.0	7.7	7.16
Total dissolved solids (mg/l)	336	474	157	160	148	518	162	250	[illegible]	[illegible]	[illegible]
Total hardness (as $CaCO_3$) (mg/l)	298	354	110	90	25	191	112	272	320	162	372
Total alkalinity (as $CaCO_3$) (mg/l)	278	354	60	66	18	300	103	273	233	118	352
Calcium (mg/l)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	98	100	31	120
Magnesium (mg/l)	9.7	6.6	14.6	7.3	2.9	44	6.6	6.3	17	21	17
Sodium (mg/l)	6.4	8.0	14.0	—	23.0	107.9	10	14.5	10	—	7.8
Potassium (mg/l)	1.6	1.0	3.9	—	2.6	7.2	1.0	[illegible]	[illegible]	—	[illegible]
Bicarbonate (mg/l)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	126	333	[illegible]	144	429
Chloride (mg/l)	21	16	25	38	38	90	18	16	30	24	17
Sulphate (mg/l)	neg[a]	neg	26	10	3	neg	nil[b]	6	22.4	—	[illegible]
Nitrate (as N) (mg/l)	4.2	0.65	5.5	3	1.1	2.1	2	1.4	5.5	6.92	3.1
Free + saline ammonia (as N) (mg/l)	0.018	0.51	0.033	nil	0.3	0.14	0.042	0.018	0.1	0.07	—
Manganese (mg/l)	nil	0.09	nil	—	0.01	nil	nil	nil	—	<0.02	—
Iron (mg/l)	0.08	0.45	neg	nil	<0.1	<0.15	0.46	0.08	0.1	<0.08	—
Principal source of material from which deposit is derived	Carboniferous limestones	Carboniferous limestones (argillaceous)	Ordovician and Silurian strata	Devonian rocks	Metamorphic strata	Carboniferous limestone and Silurian strata	Devonian sandstone rock aquifer overlain by Silurian and Devonian drift	Devonian sandstone rock aquifer overlain by Carboniferous limestone drift	Carboniferous limestone (Cullen and O'Dwyer, 1983)	Tertiary basalt	Carboniferous limestone

[a] neg, negligible.
[b] nil, zero.

BORCHOLE NUMBER AND LOCATION / PARAMETER	KNY 36/39 MULLENAKILL CO. KILKENNY	LS 31/2 SWAN CO. LAOIS	GWY 119/5 CARROWN-LISHEEN INISHMAAN CO. GALWAY	KNOCKUMBER CO. MEATH	LOUISA BRIDGE CO. KILDARE	DRUMHURRIN CO. CAVAN	CELBRIDGE CO. KILDARE	CORTOULIN BRIDGE CO. MONAGHAN	ROSSES POINT CO. SLIGO
DATE SAMPLED	MAR. '84	JUL. '76	AUG. '75	OCT. '88	DEC. '79	DEC. '85	DEC. '79		JUL. '74
LABORATORY NUMBER	GSO 113		GSO 398	GSO 286		GSO 346			
pH	5·7	8·7	7·2	8·0	7·3	7·1	7·3	7·7	7·4
TOTAL DISSOLVED SOLIDS (mg/1)	80	302	572	451	1160	2511	636	954	383
TOTAL HARDNESS (as $CaCO_3$)	16	22	284	246	432	1720	352	595	192
TOTAL ALKALINITY " "	12	251	212	330	296	29	250	301	304
CALCIUM "	0·8	4·8	101	67·2	296	616	233	172	59·2
MAGNESIUM "	3·4	2·4	7·8	19	136	44	120	40	10·7
SODIUM "	8·8	105	–	76·2	209	15·5	60	–	≃ 82
POTASSIUM "	1·9	3·2	–	3·7	9	6·7	3	–	- 1·5
BICARBONATE "	15	306	259	403	361	35	342	367	371
CHLORIDE "	19	15	94	38·2	446	13·6	142	22	31
SULPHATE "	NIL	–	23	15·5	–	1395	–	370	20
NITRATE (as N) "	2·8	–	1·9	0·02	1·4	NIL	0·5	0·7	0·4
FREE + SALINE AMMONIA " "	<0·01		–	–	0·23	-	0·15	0·14	–
ALBUMINOID AMMONIA " "	0·1		–	–	0·01	-	0·01	0·05	–
MANGANESE "	NIL		NIL	0·002	–	NIL	–	NIL	NIL
IRON "	NIL		0·3	0·09	–	0·55	–	0·5	0·14
REMARKS	SPRING	BOREHOLE	SPRING		SPRING	BOREHOLE H₂S PRESENT	SPRING	BOREHOLE	BOREHOLE.
ROCK TYPE	GRANITE SAND	SANDSTONE (AT 100M)	LIMESTONE	(AT 400M)		(DEEP)			DOLOMITE

ANALYSES BY STATE LABORATORY

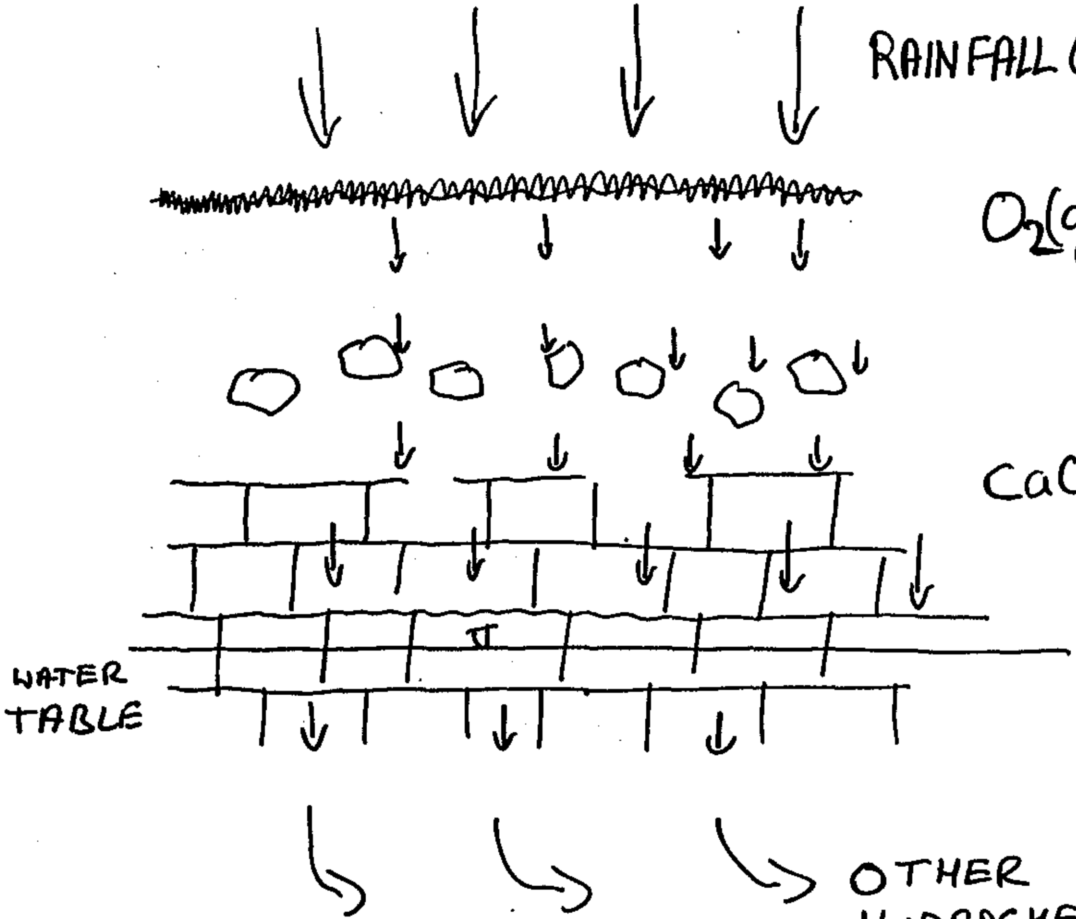
TABLE III ANALYSES OF UNUSUAL GROUNDWATERS IN IRELAND.

Station / Parameter	Belmullet, Co. Mayo	Birr, Co. Offaly	Dublin Airport	N.W. Ontario, Canada (1972)*
Electrical Conductivity µs/cm	142	46	88	
Calcium mg/l	1.35	1.22	2.74	0.53
Magnesium mg/l	2.28	0.40	0.50	0.15
Sodium mg/l	19.1	3.4	5.1	0.35
Potassium mg/l	0.91	0.19	0.45	0.14
Ammonium mg/l	0.11	0.19	0.43	0.6
Bicarbonate mg/l	1.85	2.53	3.51	-
Chloride mg/l	32	4.6	7.7	0.22
Sulphate mg/l	1.98	0.69	2.32	0.45
Nitrate mg/l	0.15	0.23	0.56	0.41
pH	5.6	5.1	6.0	5.3

* Source: Freeze and Cherry, 1979.
The remainder are from Matthews and McCaffrey, 1977 (Meteorlogical Service).

TABLE IV - Composition of rainfall at three locations in Ireland and one in Central Canada for the purposes of comparison.

RAINFALL ($O_2 + CO_2$)



$$O_2(g) + CH_2O \text{ (ORGANIC MATTER)} \rightarrow CO_2(g) + H_2O \rightarrow H_2CO_3 \text{ (CARBONIC ACID)}$$

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$

CALCITE (LIMESTONE)

OTHER HYDROCHEMICAL PROCESSES

UNCONFINED | CONFINED

$HCO_3^- \longrightarrow SO_4^{2-} \longrightarrow Cl^-$

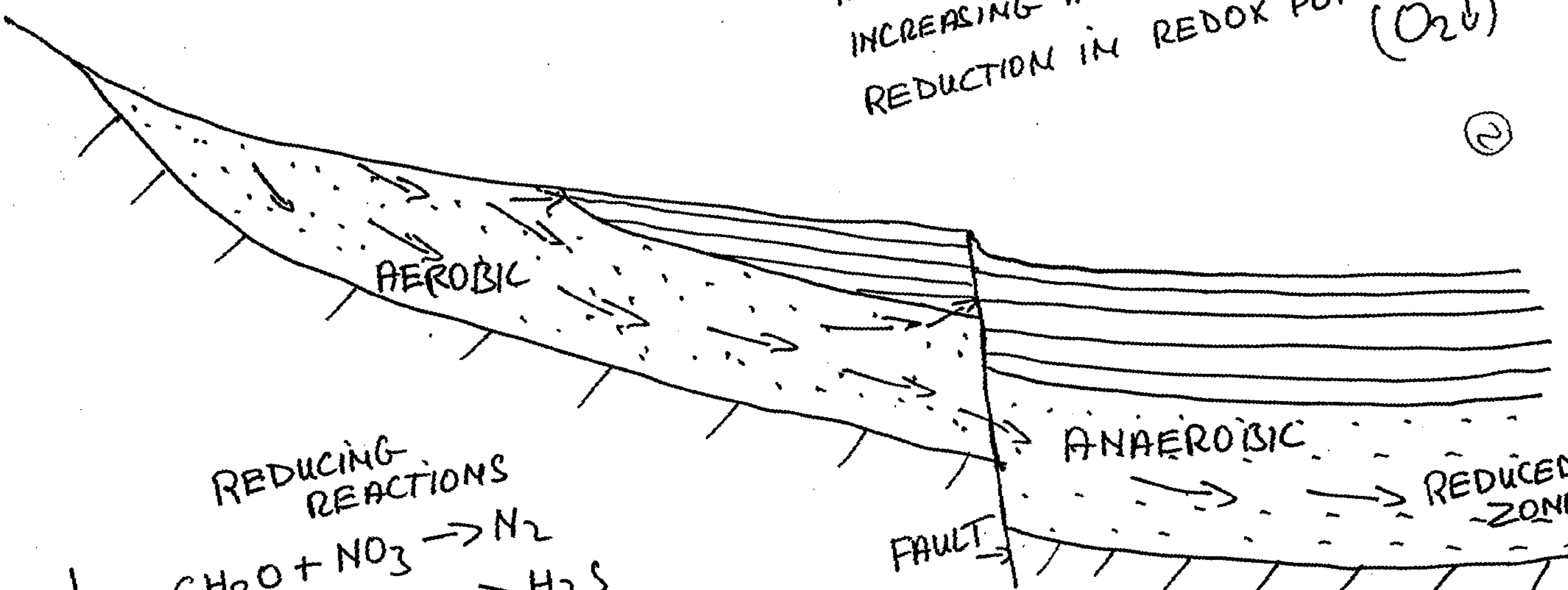
$\longrightarrow$ TRAVEL ALONG FLOW PATH

INCREASE IN TDS

INCREASING AGE/RESIDENCE TIME

REDUCTION IN REDOX POTENTIAL ($O_2\downarrow$)

(2)



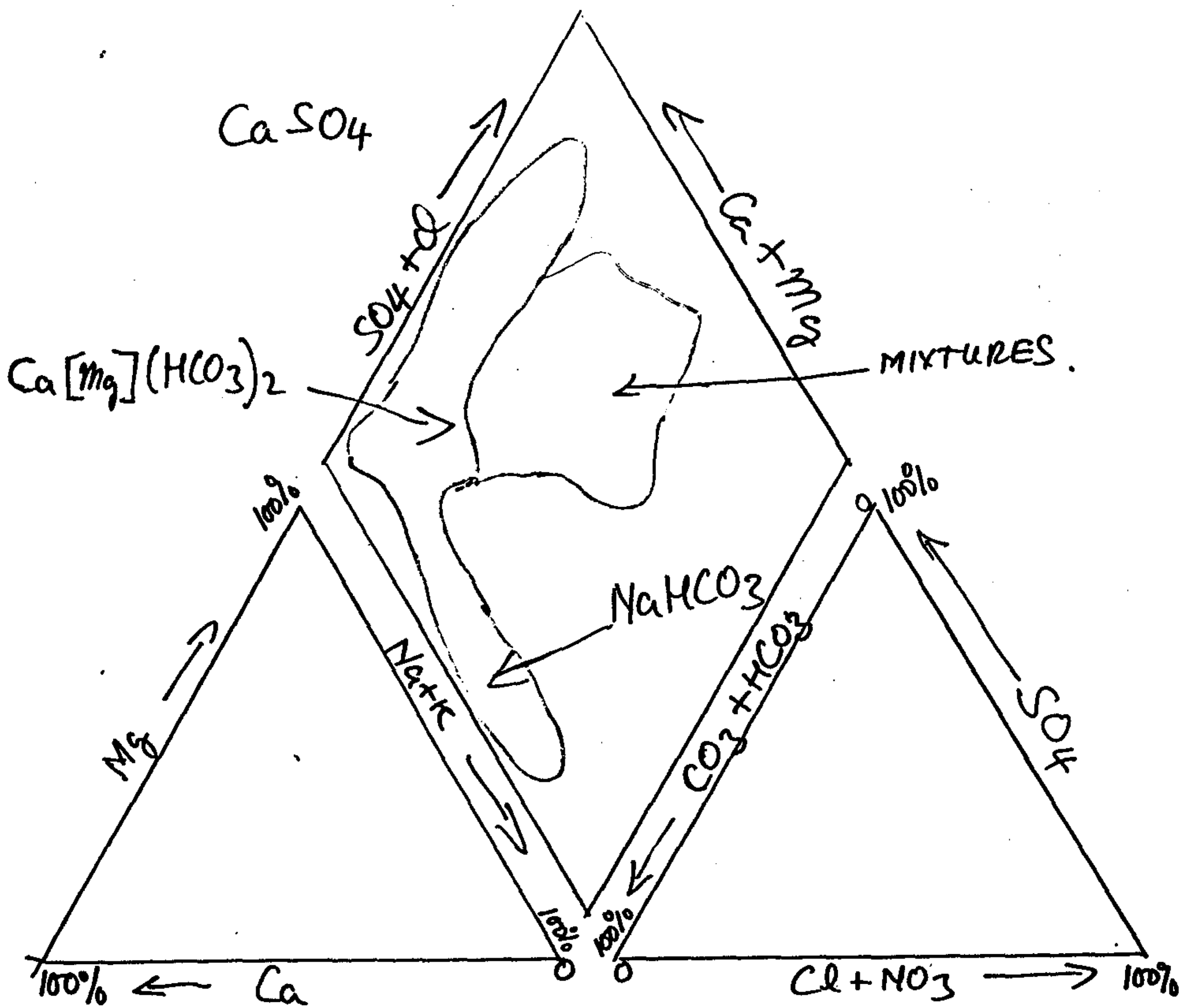
REDUCING REACTIONS

$CH_2O + NO_3 \longrightarrow N_2$

$CH_2O + SO_4 \longrightarrow H_2S$

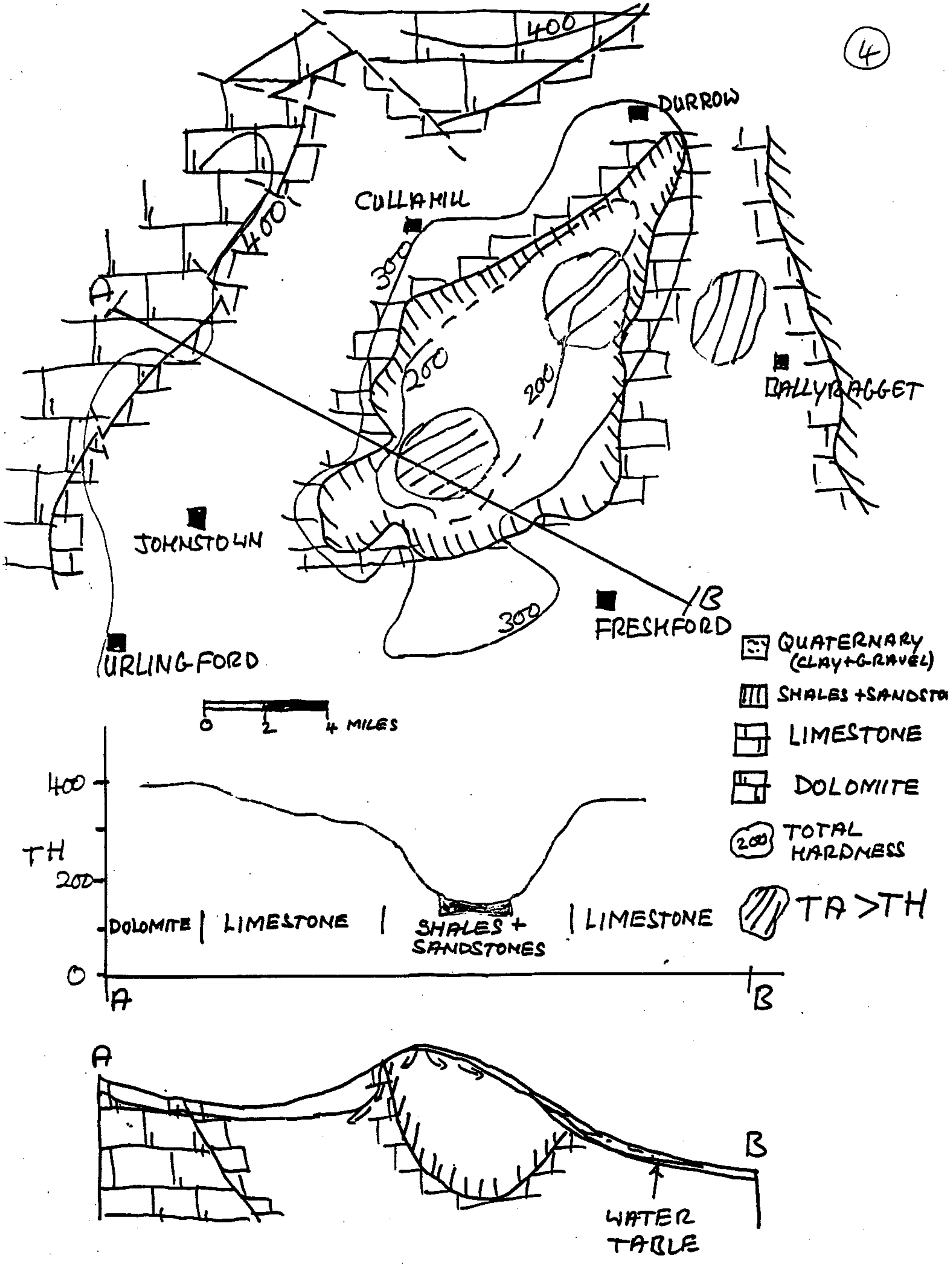
$CH_2O + H_2O \longrightarrow CH_4$

$E_h \downarrow$



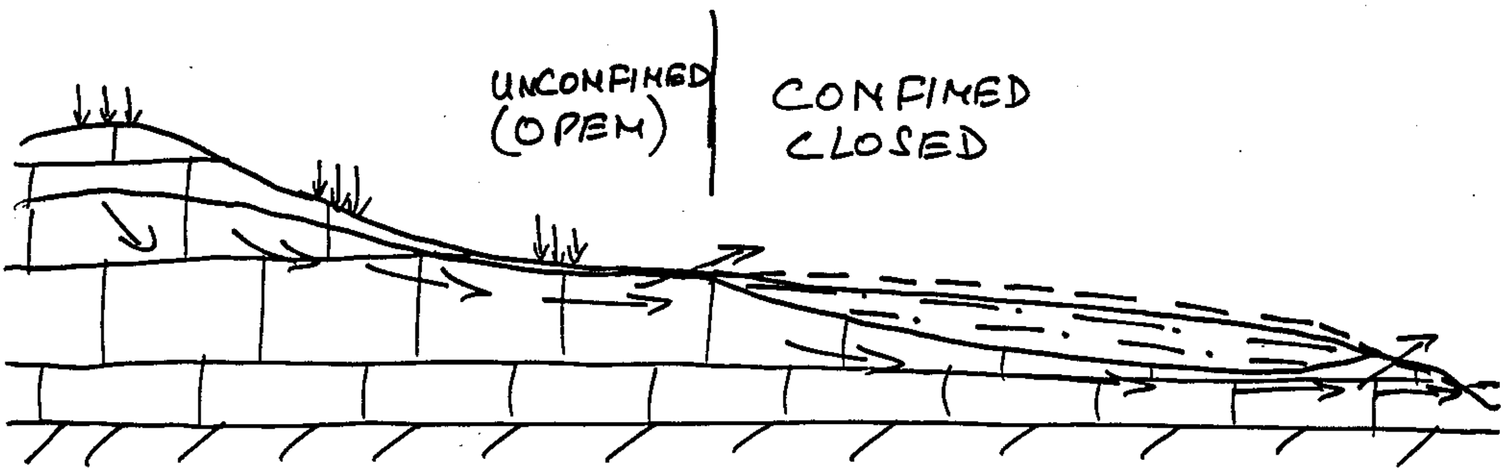
Ca SO4
SO4 + Cl
Ca + Mg
Ca[Mg](HCO3)2
MIXTURES.
NaHCO3
Mg
Na+K
CO3 + HCO3
SO4
100%
100%
100%
100%
100%
100%
0
0
Ca
Cl + NO3

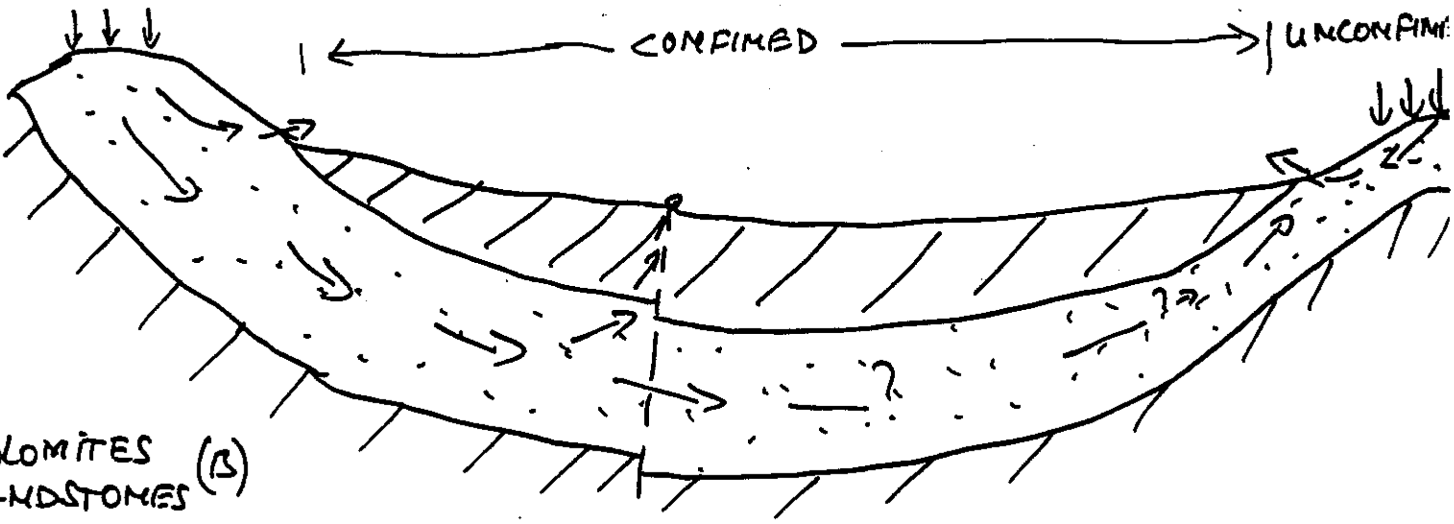
3



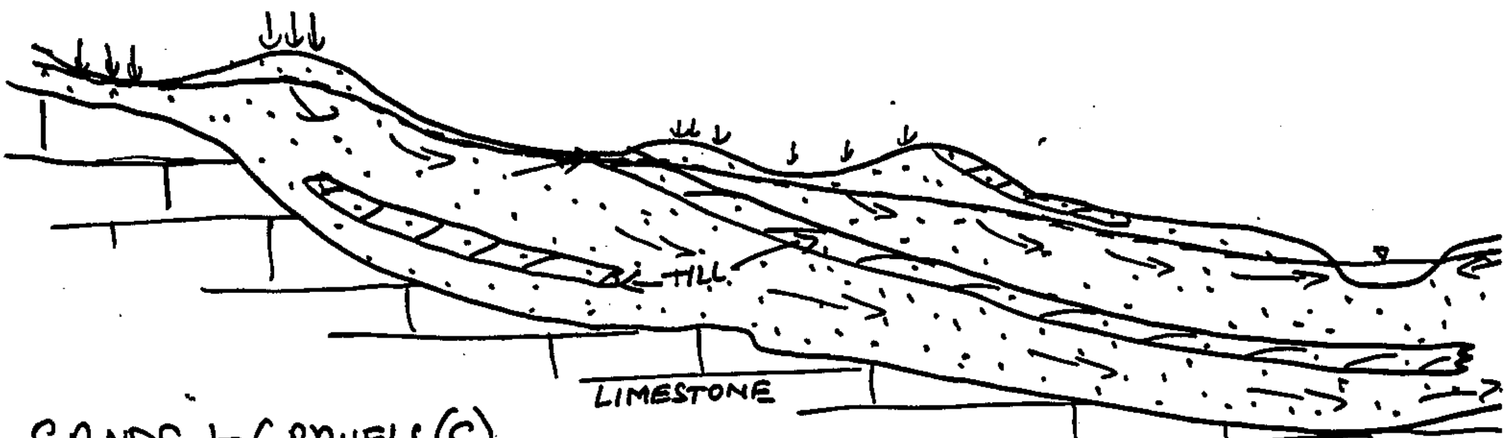
HYDROCHEMISTRY AROUND THE DURROW SYNCLINE

LIMESTONES (A)





DOLOMITES
SANDSTONES (B)



SANDS + GRAVELS (C)
OVERLYING LIMESTONES.

TYPICAL AQUIFER ENVIRONMENTS.

APPROACHES TO GROUNDWATER PROTECTION

Donal Daly and Irene Quinn*, Geological Survey of Ireland.

1. Introduction

Groundwater is a major natural resource in Ireland. It is being put at risk here as elsewhere by both the increasing number and diversity of potential pollutants. Once pollution occurs it may last for weeks, months or sometimes years. Rehabilitation is usually impractical or prohibitively expensive. Hence, groundwater protection and pollution prevention are now major issues.

Groundwater pollution risk depends on the interaction between

(a) the natural vulnerability of the aquifer, and

(b) the pollution loading that is, or will be, applied to the sub-surface environment (Foster, 1986).

Consequently, it is possible to have high vulnerability but no pollution risk, because of the absence of significant pollution loading or potentially polluting activities, and vice versa. It is worth remembering that vulnerability is an intrinsic characteristic of an aquifer whereas pollution loading can be controlled or modified.

This paper briefly describes the factors that influence groundwater vulnerability and the ways, including vulnerability mapping, that they are assessed. Vulnerability ratings are suggested for different hydrogeological settings. A general groundwater protection strategy is recommended for local authorities which takes account of groundwater resources, groundwater vulnerability assessments and the location and regulation of potentially polluting activities. Aspects of this strategy are relevant to industrialists in both the bottled waters and fish farming areas. .

2. Factors Influencing Groundwater Vulnerability to Pollution.

2.1 General

The geological materials above the water table provide groundwater with natural protection against pollution. The degree of protection or vulnerability varies greatly, depending on a number of inter-related geological and hydrogeological factors which are listed below and summarised in Table 1:

* Now a Quaternary geological consultant.

(a) Type (lithology) of subsoil (unconsolidated, largely Quaternary deposits);
(b) Permeability of subsoil;
(c) Thickness of subsoil over bedrock;
(d) Type of permeability - intergranular or fissure;
(e) Thickness of unsaturated zone;
(f) Attenuating capacity of subsoil and bedrock:
(g) Type of recharge.

2.2 Influence of Subsoil (Quaternary Deposits).

The subsoil or Quaternary deposits are the first line of natural defence against pollution and act as a protecting filtering layer over the water table by physical and chemical/ biochemical means. Fortunately they cover over 90% of the land surface of Ireland. Fine-grained sediments such as clayey till (boulder clay), clays and peats with a low permeability can act as a barrier to the vertical movement of pollutants. Even if the permeability is moderate and allows slow intergranular movement of pollutants, for instance in sandy, free-draining tills, the sediments can strain out and absorb bacteria and viruses. In contrast high permeability deposits - clean sands and gravels - allow easy access of pollutants to the water table although they provide opportunities for dispersion of the pollutants among the pore spaces.

Sorption, ion exchange and precipitation are vital chemical processes in attenuating pollutants. The effectiveness of these processes depends on the clay and organic contents - the higher they are, the greater the attenuation.

2.3 Influence of Permeability Type.

The presence of intergranular permeability in an aquifer aids the attenuation and breakdown of pollutants as it is associated with a relatively low flow rate which helps filtration and interactions between the pollutants and rock grains. The permeability in the Quaternary deposits - sands, gravels, clays and peats - is intergranular. In contrast a fracture permeability, which is present in bedrock, allows more rapid flow rates and provides less scope for rock/pollutant interactions and consequently less attenuation of the pollutants.The worst situation is in karst limestones where flow rates can vary from 6 to 600m/hr and there is little scope for attenuation.

2.4 Importance of Unsaturated Zone.

The unsaturated zone, like the subsoil, has a strategic position between the land surface and the water table and acts as a favourable environment for pollutant attenuation. As water movement in the unsaturated zone of the subsoil is normally slow and in an aerobic and alkaline environment, there is good potential for beneficial physical, chemical and biological processes to attenuate the pollutants. In contrast an unsaturated zone in fissured rocks may not significantly aid attenuation as water and pollutant flow rates are relatively high.

In the case of persistent, mobile pollutants, such as nitrates and certain trace organics, there is little beneficial attenuation in the unsaturated zone, which only provides a lag-time before arrival at the water table.

2.5 Influence of Recharge Type.

Groundwater is extremely vulnerable to pollution in karstified limestone areas with sinking streams. In this situation polluted surface water can recharge aquifers with minimal attenuation.

Table 1
Geological/Hydrogeological Factors and Degree of Protection

GOOD PROTECTION	POOR PROTECTION i.e. vulnerable
1. High clay or peat content.	1. Low clay or peat content.
2. Low permeability subsoil e.g. clayey till, peat.	2. High permeability subsoil e.g. sand and gravel.
3. Thick (greater than 5m) subsoil.	3. Thin subsoil.
4. Intergranular flow.	4. Fissure or karstic flow.
5. Thick unsaturated zone.	5. Thin unsaturated zone.
6. Recharge by percolation through soil and subsoil.	6. Recharge by sinking streams.

3. Groundwater Vulnerability Assessment.

There are two main approaches to vulnerability assessment;

(a) vulnerability mapping using geological and hydrogeological data and

(b) using water quality data.

3.1 Vulnerability Mapping.

This is the technique of assessing all the geological and hydrogeological factors and ranking the vulnerability of groundwater and displaying it on a map in a manner which is understandable and useful. Vulnerability maps can be prepared using existing geological, depth to bedrock and hydrogeological data and preferably supported by short reconnaissance surveys. Hydrogeological expertise is essential in preparing these maps.

Figure 1 illustrates a basic vulnerability map in the vicinity of a spring in the Midlands together with maps showing the geological and hydrogeological information. These maps, which were compiled at 1:25,000 scale, are based on existing data on Geological Survey files, examination of aerial photographs, discussions with local authority staff and a three-day reconnaissance survey by a Quaternary geologist. A detailed discussion of the vulnerability assessment will not be given in this paper. However, it is worth noting how a brief assessment of the probable recharge area of this spring draws attention to significant aspects such as the presence of relatively high permeability sandy till over much of the area, the shallow till in the vicinity of the intermittent stream and the karst features - sink holes, scarcity of surface streams, intermittent streams, possible collapse features and turloughs.

Vulnerability mapping can be used in the protection of water supplies for local authority and industrial use.

3.2 Vulnerability Assessment Using Water Quality Data.

The vulnerability of wells and springs can be placed within decreasing pollution risk categories based on either existing or readily obtainable groundwater quality data. Hardness (in limestone areas), conductivity, temperature and bacteriological data are usually appropriate parameters. The variations in hardness and/or conductivity levels in response to recharge between groundwater sources can enable comparison of the degree of vulnerability to pollution. It is reasonable to assume that the more rapid the response to recharge and the greater the variations the more vulnerable the source is to pollution. Regular measurements - fortnightly should be adequate - are needed for this technique. (Further information on temporal groundwater quality variations in different hydrogeological settings are given in the papers by Dr. C. Coxon and Dr. R. Thorn in these proceedings). Wells or Springs can also be placed within decreasing pollution risk categories based on whether bacterial pollution is regular, occasional or absent.

This type of assessment can enable engineers in local authorities to give priority to the more vulnerable sources when preparing protection policies.

3.3 Vulnerability Rating and Hydrogeological Setting.

Vulnerability ratings for different typical Irish hydrogeological settings are given in Table 2. These ratings are subjective and qualitative. This is inevitable as geological and hydrogeological knowledge will normally be inadequate to enable quantitative and impartial ratings to be determined.

However, provided the limitations are appreciated, vulnerability assessments can be a powerful tool in protecting groundwater.

Table 2

Vulnerability Rating	**Hydrogeological Setting**
Extreme:	1. Outcropping bedrock aquifers (particularly karst limestone) or where overlain by shallow (less than 3m*) subsoil.
	2. Sand and gravel aquifers with a shallow (less than 3m*) unsaturated zone.
	3. Areas near karst features such as sink holes.
High:	1. Bedrock aquifers overlain by 3m+ sand and gravel or 3-10m sandy till or 3-5m low permeability clayey tills or clays.
	2. Unconfined sand and gravel aquifers with 3m+ unsaturated zone.
Moderate:	1. Bedrock or gravel aquifers overlain by 10+ sandy till or 5-10m clayey till, clays or peat.
Low:	1. Confined bedrock or gravel aquifers overlain by 10m+ clayey tills or clays, or low permeability bedrock such as shales.

* Note: In theory less than 1m subsoil or unsaturated zone beneath a development rather than 3m should be the cut-off depth for the "extreme" rating. However, taking a thickness of 3m rather than 1m is regarded as more practical and useful for the following reasons: (a) the base of many developments - septic tank systems or farmyard effluent holding tanks for instance - are 1-3m b.g.l.; (b) in preparing a vulnerability map the general rather than the site specific situations must be taken into account; and (c) a 3m cut-off depth allows for lateral variations and often provides a safety margin. Obviously if the base of a potentially polluting development is more than 3m deep, the rating classification may be affected.

4. Assessment of Groundwater Pollution Loading.

Vulnerability assessments of any area by themselves do not provide a system of groundwater protection. They have to be linked to surveys and assessments of existing potentially polluting activities, and a code of practice for locating and regulating existing and new developments.

One method of taking account of the pollution loading is to overlay the vulnerability map with a map showing the locations of existing potentially polluting developments. An assessment of pollution risk is then possible. Also local authority staff can give priority to monitoring the developments placing groundwater at most risk.

5. An Overall Groundwater Protection Strategy.

The Geological Survey recommends the following strategy for the protection of groundwater. It is comprised of three components:

1. A regional groundwater protection scheme which includes vulnerability mapping and takes account of the total groundwater resources.
2. A source protection zone around major public and industrial groundwater supplies which is influenced by the vulnerability mapping technique.
3. Site investigations where necessary.

The first stage involves the production of a map which divides any area, such as a local authority area, into a number (usually four) aquifer protection zones according to the degree of protection required, Zone 1 requiring the highest degree of protection and Zone 4 the least. Zone 1 is a source protection zone around each designated public groundwater supply source. It is subdivided into three subzones; 1A, 1B and 1C. Zone 1A is the area within 10m from the source, Zone 1B is the area between radii 10-300m and Zone 1C is the area between radii 300-1000m. Zone 2 comprises the major aquifers, Zone 3 the minor aquifers and Zone 4 the non-aquifers and aquifers which have adequate natural protection from pollution. A code of practice is prepared which lists the generally acceptable and unacceptable activities for each zone and describes the recommended controls for developments. For further information see Daly (1986).

The second stage is to refine and improve the scheme by carrying out a vulnerability assessment including the preparation of vulnerability maps at 1:100,000 or 1:50,000 scales. Larger scale maps - 1:25,000 or 1:10,000 - are preferable for the source protection zones. The maps shown in Figure 1 were prepared for a source protection zone.

The third stage is to prepare an inventory and map of potentially polluting developments. The fourth stage is to carry out site investigations, if necessary.The final stage is to refine the code of practice and the zonal boundaries based on the information collected in stages 2 and 3.

6. Uses of Groundwater Protection Schemes and Vulnerability Assessments.

A well prepared groundwater protection scheme has the following benefits and uses:

1. It brings the groundwater interest to the attention of decision-makers and makes information widely available.
2. It assists planners and engineers in locating and regulating potentially polluting activities:
   - by contributing to the search for a balance of interests between water protection issues and other social and economic factors;

- by assisting in the preparation of development, water quality and waste management plans;
- by setting priorities for technical resources, as they provide a hierarchy of levels of concern;
- by acting as a guide for local authority staff and providing a "first-off" warning system which can be used before site visits or investigations are made;
- by controlling developments and encouraging them in areas of least concern, it helps to ensure that the Local Government (Water Pollution) Act, 1977, is not contravened.

3. It assists local authorities in making water treatment investment decisions.
4. It enables more detailed and expensive investigations to be directed where the threat is greatest.
5. It enables industrial users to assess pollution risk either before or after developing a groundwater source.

However, protection schemes are not a panacea for solving all problems. They are not a substitute for site visits or investigations. Vulnerability maps are somewhat subjective and qualitative and depend on the available data. Also they generalise situations which may have highly variable geological conditions. They may not be suitable for considering very hazardous, mobile pollutants such as trace organics. There is a danger that protection schemes would be applied too literally and simplistically. The code of practice should be realistic and should not be too rigid.

It is considered that the advantages considerably outweigh the disadvantages because, by identifying options, protection schemes provide a positive contribution to multiobjective planning in a multifunctional organisation such as a local authority. Likewise for industries requiring high quality groundwater, they are an aid in decision-making.

7. References.

DALY, D. 1986. Groundwater Protection and Planning. Internal Report. Geological Survey of Ireland. 16pp.

FOSTER, S.S.D. 1987. Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. Proceedings of the International Symposium "Vulnerability of soil and groundwater to pollutants". The Netherlands. pp. 69-86.

8. Acknowledgement.

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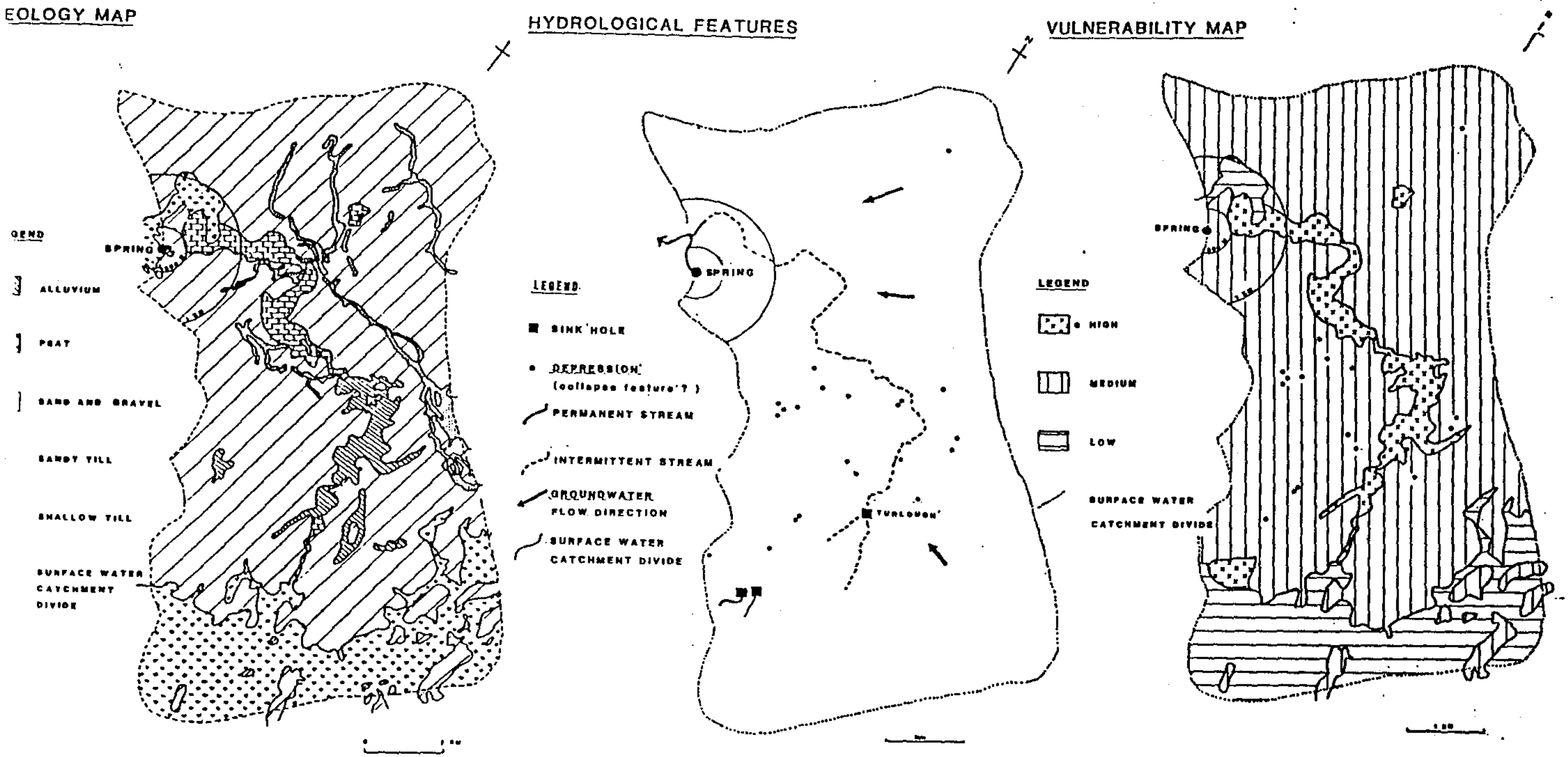


(These maps are reduced copies of the original 1:25,000 scale maps).

FIGURE 1. GEOLOGY, HYDROGEOLOGICAL FEATURES AND VULNERABILITY MAPS FOR SPRING CATCHMENT AREA.

STANDARDS & CERTIFICATION FOR BOTTLED WATERS.

Richard Foley, Ph.D.
Water Environment Dept., EOLAS.

1. Introduction.

The markets of particular interest to most Irish producers of bottled waters are Europe and North America. Other markets such as Japan are being explored by some producers. To secure an adequate return on investment export is essential, as despite a growing home market, it will never be big enough for the number of competitors already established. Accordingly producers and potential producers must know the basic requirements of the regulatory authorities in the market of interest.

In a short presentation it is impossible to deal with all the markets and so attention will be focused on the European Community (EC) and United States.

2. European Community.

2.1 Natural Mineral Water.

In the mid-seventies the Commission decided that some regulation of the trade in bottled water and natural mineral water was necessary. Specifically they were concerned that (a) national requirements of individual states constituted barriers to free trade (b) doubtful claims as to the medical or health benefits were being made (c) microbiologically unfit products were on the market (d) some sources were contaminated or were at serious risk from contamination and

(e) the standard of bottling practice left a lot to be desired.

Finally in 1980 a directive appeared (80/777/EEC, OJ L229/1 - 10, 30 August 1980) and it was given legal status in Ireland with the making of regulations by the Minister of the then Department of Industry, Trade, Commerce and Tourism. (European Communities (Natural Mineral Waters) Regulations, 1986, S.I. No 11 of 1986, 20 January 1986). It is clear that there was a very strong input from the French, Germans and Italians as many of their stringent national regulations were incorporated almost verbatim into the directive. Responsibility for the directive and Irish Regulations has since passed to the Department of Agriculture and Food.

It is most important to note that the directive applies only to products described as natural mineral water and offered for sale within the EC.

The directive puts in place a scheme for the recognition and exploitation of sources as natural mineral waters by national responsible authorities. The Irish Regulations designated EOLAS (then IIRS) as the "Responsible Authority". Strictly it is the National Standards Authority of Ireland (NSAI) that grants recognition and permission to exploit a source. The NSAI is a sub-board of the main EOLAS board and one of its main activities is the issue of Irish standards which have legal status.

The directive contains 17 articles and three annexes. In a nutshell it states that only the purest of groundwaters with no organoleptic defect may be bottled and marketed as natural mineral waters (NMW's) within the EC. Furthermore these products must have been recognised by the responsible authority. A product that has not been recognised may not be called a natural mineral water despite the fact that its composition and purity may be excellent. A summary of the main objectives of each article is given in Table 1.

TABLE 1: A summary of the objectives of the articles in the "Mineral Water Directive"

Article	Objective
1	Scope of Directive; compliance with Annex I
2	Obligation on member states to ensure that products marketed as NMW comply with Directive.
3	Requirements for exploitation of source; compliance with Annex II - prohibition of transport to bottling plant.
4	Prohibition of treatments; exemptions and allowed treatments listed eg.,removal of iron and sulphur by oxidation, decanting, filtration etc., provided no change caused to essential characteristics particularly bacteriological quality
5	Microbiological criteria; at source and in the bottle during marketing. Source must be free from pathogenic microorganisms. Maximum total bacterial count - 100 cols/ml @ 20 - 22 ^{o}C & 20 cols/ml @ 37 ^{o}C.
6	Bottle security - tamper proof closures
7	Sales description requirements and restrictions; carbonation method; declaration of analytical composition.
8	Labelling requirements - name of source and place of source (NB Separate EC Product Labelling Directive also applies)
9	Restrictions on claimed health benefits; compliance with Annex III.
10 - 17	Miscellaneous provisions.

Table 2: Characteristics of Irish, Other European NMW and US Bottled Water

PARAMETER	Perrier	Evian	Glenpatrick	Tipperary	Ballygowan	Vittel	S.Pellegrino	Carolina	Apollinaris	Mount.Valley
pH	—	7.2	7.5	7.6	6.9	—	7.3	—	—	—
Calcium	140	78	110	38	130	202	212	5	91	79
Magnesium	3	24	17	24	8	36	55	1	122	7
Sodium	14	5	13	19	17	3	45	4	630	3
Potassium	1	1	1.2	15	3	—	4	—	33	1
Bicarbonate	348	357	455	139	350	402	225	—	2062	238
Sulphate	51	10	24	10	15	306	560	—	158	8
Chloride	31	2	25	16	30	—	67	1	203	4
Nitrate	0	3.8	4	2.2	1.2	—	0.8	0	—	—
Dissolved Solids	—	309	321	280	480	—	1116	26	—	—

To obtain recognition as a NMW an applicant makes a submission to the NSAI. The submission is of great importance because it will be assessed against the stipulated requirements in Annex I and if any point is not covered then the application will either be rejected or at the very least delayed while further information or clarification is prepared and resubmitted. Very detailed technical information is required to cover adequately several of the points and for this reason intending applicants should consider employing a hydrogeologist to prepare the submission, at least in part. Indeed, if a hydrogeologist is employed early enough in the project he or she may well advise against proceeding with a given source if it becomes apparent that it is not a good one. The full text of Annex I is given in the Appendix to this paper.

It is worth emphasising that the geology and hydrogeology of the source must be described in detail. The general geology and activities eg., tillage, dairying, forestry etc. carried out in the locality must also be described.

With the exception of Article 5, microbiological criteria, no other limit values are laid down in the Directive. It is very important to note that there is no minimum concentration for total dissolved solids (TDS) in order to qualify for NMW status. If there was then the consumer's choice would be limited and there is a significant segment of the market that has a preference for low mineral content waters. The range of characteristics for well known products is shown in Table 2. In passing it may be noted that some of these exceed EC drinking water standards (Directive 80/778/EEC).

Water analysis and bacteriological examination results must obviously form part of the submission. The NSAI generally requires the results of analysis of several samples taken over a period of not less than six months. Ideally the samples should be taken every two months over a twelve month period. The parameters to be determined are shown in Table 3. The purpose of this requirement is to demonstrate that there is no undue seasonal or climatic effect on the water's chemical composition or microorganism content. In addition the data will be assessed for evidence of organic contamination which the bacteriological results might not indicate.

Table 3: Parameters Required to Demonstrate Constancy of Mineral Composition and General Organic Quality.

pH	Calcium	Magnesium
Sodium	Potassium	Iron
Manganese	Bicarbonate	Carbonate
Chloride	Sulphate	Ammonium
Nitrate	Nitrite	Tot.Org.Carbon
Elec.Conductivity	Temperature	Phosphate
Free Carbon Dioxide	Fluoride	Silica

Table 4: Bacteriological Examination.

Total coliforms E.coli F.Streptococci

Total Viable Counts at 20 - 22 and 37 ^{o}C

Sporulated sulphite-reducing anaerobes

Pseudomonas aeruginosa

Parasites and pathogenic microorganisms

At least one of samples taken must be analysed for the parameters listed in Table 5. These are, by and large, the undesirable, toxic and dangerous substances. In a good quality water these will either be absent or present at concentrations below the analytical detection limit. It is of interest to note that for many years the French would not allow the import of certain NMW's which contained a minute trace of arsenic. These particular products were the brand leaders in their own countries.

Table 5: List of Undesirable, Toxic or Dangerous Substances.

GROUP 1 - Toxic and Dangerous Substances
Maximum Concentrations in ug/l.

Lead	10	Arsenic	50	Cyanide	50
Cadmium	5	Chromium	50	Selenium	10
Nickel	50	Antimony	10	Mercury	1

Group 2 - Undesirable Substances.

Copper	Zinc	Aluminium
Cobalt	Strontium	Lithium
Barium	Iodine	Bromine
Sulphide	Molybdenum	Silver

It is not uncommon for the Responsible Authorities in other member states to require analysis for a large range of pesticides, herbicides and synthetic organic chemicals as well as the parameters listed in Tables 3 and 4. This is certainly desirable in countries where these chemicals are manufactured or where they are used intensively. However this is not generally the case in Ireland but if an applicantion was made for a source in a heavily industrialised region or an area where intensive horticulture was practiced say, then some additional analysis would almost certainly be required.

When a laboratory is engaged to carry out analysis, those submitting the samples should ensure that the laboratory is under the direction of a qualified analytical chemist and that the staff are qualified. Similarly, bacteriological examinations should be supervised by a microbiologist. The NSAI will if there is any doubt about the competance of the laboratory insist on examining the quality control records and may have fresh samples independently analysed. Where in-house facilities only are used, independent sampling and analysis will be done to verify the results.

Even though a water may be of excellent quality, the assessment will include a detailed examination of the immediate area surrounding the source and the genaral area of the locality to ensure that no activities that could pose a threat to quality are taking place. For example, a nearby intensive animal feed unit with attendant slurry tanks would be deemed a significant risk. Proximity of underground fuel tanks etc would also be considered risky. Sources adjacent to built up areas with no central foul drainage would be most unlikely to be recognised. It follows from this that those who have recognised sources should pay particulat attention to proposed nearby developments to ensure that the risk of contamination is not increased.

If a source does become contaminated (for whatever reason) or if a significant change in mineral composition occurs, then permission to exploit will be withdrawn and recognition revoked if it clear that the cause cannot be either identified or corrected. If permission to exploit is withdrawn it does not necessarily mean that recognition will also be revoked.

It should be noted that the NSAI's responsibility in the matter of recognition is concerned only with the source itself. Permission to exploit is a separate matter and is dependent on factors such as the design, layout and operation of the bottling plant, hygiene, storage of finished product etc. The NSAI also conducts regular spot checks to ensure that the conditions attached to the recognition and permission to exploit are being observed.

2.2 Bottled "Spring" Water.

As noted earlier, the Directive is concerned with products described as NMW. What is the status of the so-called "Spring" or "Table" etc waters as far as regulation is concerned ?. In the case of Ireland and the UK the Drinking Water Directive applies to what is actually offered for sale. Some discussion is taking place in the Dept of Food and Agriculture concerning possible regulation of non-NMW products.

In the rest of the Community there is considerable variation. For example, the Dutch Government enacted the NMW Directive twice, once for the NMW's and the second time with minor changes to cover all other bottled water. France, Germany and Italy already had extensive stringent legislation long before the Directive and this is still in place. Thus an Irish product marketed as "Ballydehob Spring water" will be more difficult to export to West Germany than a recognised NMW. On the face of it obtaining NMW recognition appears to be the easiest route to gaining access to the EC countries.

3. The United States.

Bottled mineral water is considered to be a food in the United States and is subject to the Federal Food Drink and Cosmetic Act. Retail sales are covered by the Fair Packaging and Labeling Act.

Bottled water is subject to the above Acts but also to the US Food and Drugs Administration (FDA) code of good manufacturing practice. This contains maximum concentration limits of 250 mg/l for sulphate and chloride and 500 mg/l for dissolved solids as well as limits for other parameters. Mineral waters are exempted from the Code's quality standards but all other provisions apply. It is clear that the US differentiates between bottled and mineral water.

There is still further potential regulation at state, county and city level. For example, the State of California requires any product that contains in excess of 500 mg/l of dissolved solids to be described as a mineral water. Currently there is a proposal before the Commonwealth of Massacheuttes that in order to describe a product as mineral water it must contain a minimum of 500 mg/l of dissolved solids. The European Commission is actively resisting this move.

There is a general requirement in the US for almost sterile products and to this end regulatory bodies actively encourage the use of disinfectants such as chlorine and particularly ozone since this leaves no residue. This contrasts sharply with the EC Directive where such treatments are expressly prohibited, the emphasis being on selection of only the highest bacter- iological quality sources for recognition in the first place. US regulations actually permit tap water to be bottled and sold as bottled water !

The State authorities usually require analytical data for most of the parameters in Table 4 and also for trihalomet-hanes (THM's). The fact that a product may have EC NMW status does not, unfortunately, guarantee easy entry to the US but it certainly helps. The best advice that can be given at the moment to those who would like to export to the US is to find out at State level what exactly their requirements are.

APPENDIX 1

ANNEX I

I. DEFINITION

1. 'Natural mineral water' means microbiologically wholesome water, within the meaning of Article 5, originating in an underground water table or deposit and emerging from a spring tapped at one or more natural or bore exits.

Natural mineral water can be clearly distinguished from ordinary drinking water:

(a) by its nature, which is characterized by its mineral content, trace elements or other constituents and, where appropriate, by certain effects;

(b) by its original state,

both characteristics having been preserved intact because of the underground origin of such water, which has been protected from all risk of pollution.

2. These characteristics, which may give natural mineral water properties favourable to health, must have been assessed:

(a) from the following points of view:

1. geological and hydrological,
2. physical, chemical and physico-chemical,
3. microbiological,
4. if necessary, pharmacological, physiological and clinical;

(b) according to the criteria listed in Section II;

(c) according to scientific methods approved by the responsible authority.

The analyses referred to in (a) (4) may be optional where the water presents the compositional characteristics on the strength of which it was considered a natural mineral water in the Member State of origin prior to the entry into force of this Directive. This is the case in particular when the water in question contains, per kg, both at source and after bottling, a minimum of 1 000 mg of total solids in solution or a minimum of 250 mg of free carbon dioxide.

3. The composition, temperature and other essential characteristics of natural mineral water must remain stable within the limits of natural fluctuation; in particular, they must not be affected by possible variations in the rate of flow.

Within the meaning of Article 5 (1), the normal viable colony count of natural mineral water means the reasonably constant total colony count at source before any treatment, whose qualitative and quantitative composition taken into account in the recognition of that water is checked by periodic analysis.

II. REQUIREMENTS AND CRITERIA FOR APPLYING THE DEFINITION

1.1. Requirements for geological and hydrological surveys

There must be a requirement to supply the following particulars:

1.1.1. the exact site of the catchment with indication of its altitude, on a map with a scale of not more than 1 : 1 000;

1.1.2. a detailed geological report on the origin and nature of the terrain;

1.1.3. the stratigraphy of the hydrogeological layer;

1.1.4. a description of the catchment operations;

1.1.5. the demarcation of the area or details of other measures protecting the spring against pollution.

1.2. Requirements for physical, chemical and physico-chemical surveys

These surveys shall establish:

1.2.1. the rate of flow of the spring;

1.2.2. the temperature of the water at source and the ambient temperature;

1.2.3. the relationship between the nature of the *terrain* and the nature and type of minerals in the water;

1.2.4. the dry residues at 180 °C and 260 °C;

1.2.5. the electrical conductivity or resistivity, with the measurement temperature having to be specified;

1.2.6. the hydrogen ion concentration (pH);

1.2.7. the anions and cations;

1.2.8. the non-ionized elements;

1.2.9. the trace elements;

1.2.10. the radio-actinological properties at source;

1.2.11. where appropriate, the relative isotope levels of the constituent elements of water, oxygen (^{16}O — ^{18}O) and hydrogen (protium, deuterium, tritium);

1.2.12. the toxicity of certain constituent elements of the water, taking account of the limits laid down for each of them.

1.3. Criteria for microbiological analyses at source

These analyses must include:

1.3.1. demonstration of the absence of parasites and pathogenic micro-organisms;

1.3.2. quantitative determination of the revivable colony count indicative of faecal contamination:

(a) absence of Escherichia coli and other coliforms in 250 ml at 37 °C and 44·5 °C;

(b) absence of faecal streptococci in 250 ml;

(c) absence of sporulated sulphite-reducing anaerobes in 50 ml;

(d) absence of Pseudomonas aeruginosa in 250 ml.

1.3.3. determination of the revivable total colony count per ml of water:

(i) at 20 to 22 °C in 72 hours on agar-agar or an agar-gelatine mixture,

(ii) at 37 °C in 24 hours on agar-agar.

1.4. Requirements for clinical and pharmacological analyses

1.4.1. The analyses, which must be carried out in accordance with scientifically recognized methods, should be suited to the particular characteristics of the natural mineral water and its effects on the human organism, such as diuresis, gastric and intestinal functions, compensation for mineral deficiencies.

1.4.2. The establishment of the consistency and concordance of a substantial number of clinical observations may, if appropriate, take the place of the analyses referred to in 1.4.1. Clinical analyses may, in appropriate cases, take the place of the analyses referred to in 1.4.1 provided that the consistency and concordance of a substantial number of observations enable the same results to be obtained.

III. SUPPLEMENTARY QUALIFICATIONS RELATING TO EFFERVESCENT NATURAL MINERAL WATERS

At source or after bottling, effervescent natural mineral waters give off carbon dioxide spontaneously and in a clearly visible manner under normal conditions of temperature and pressure. They fall into three categories to which the following descriptions respectively shall apply:

(a) 'naturally carbonated natural mineral water' means water whose content of carbon dioxide from the spring after decanting, if any, and bottling is the same as at source, taking into account where appropriate the reintroduction of a quantity of carbon dioxide from the same water table or deposit equivalent to that released in the course of those operations and subject to the usual technical tolerances;

(b) 'natural mineral water fortified with gas from the spring' means water whose content of carbon dioxide from the water table or deposit after decanting, if any, and bottling is greater than that established at source;

(c) 'carbonated natural mineral water' means water to which has been added carbon dioxide of an origin other than the water table or deposit from which the water comes.

The Bottled Water Boom

by

Timothy Green

(Mr. Green is co-author and publisher of

The Good Water Guide)

Drinking water is fashionable again. A century ago it was the custom to visit elegant spas to 'take the waters' and cure all manner of ailments. Today, in an era increasingly concerned about health, diet and pollution of the environment, mineral and natural spring waters are back in vogue. This shift in drinking habits away from strong spirits to lighter wines, and some sugary soft drinks to bottled waters is world-wide. In the US bottled water has been the fastest-growing beverage in recent years (even Time and Newsweek have done cover stories on the boom). But it is Britain which has experienced (and still is) perhaps the most phenomenal growth. In the mid-70s (about twelve years ago) the UK retail market was worth about £2 million; in 1988 it was £130 million - up 65 times in money terms. As the Financial Times has observed, this reflects 'a major shift in drinking habits'.

What has brought it about? And more important, in the context of this conference, when will the boom end? To give you an immediate short answer to the latter question: no end is in sight. The bottled water market in Britain is still growing by about 30 per cent annually. Indeed, in the drinks sector it is quite a growth league of its own. One leading supermarket chain, doubled its shelf space, for water last year. Significantly this year, Marks & Spencer, with nearly 300 stores, has given water shelf sapce for the first time in a link-up with France's Vittel.

But at the outset, let us try to set this boom into a broader context. To many Europeans, of course, drinking mineral waters is nothing new. The French consume nearly 75 litres per head annually (thirty-five times the British consumption), and the Belgians, Germans and Italians all soak up close to sixty litres (thirty times the British). In Spain and Portugal it is about 25 litres. In much of Europe it is natural to order a bottle of wine and a bottle of mineral water to complement a good meal in a restaurant. West Germans and Austrians also often mix mineral water with white wine to make a 'spritzer' at parties, to cut down alcohol intake. The natural Italian reaction in any crisis, whether a strike or an earthquake, is to rush out to stock up on bread, wine and mineral water, the basic necessities of life. And an Italian going into hospital traditionally arrives with a bottle of pure Sangemini tucked under his arm.

The connoisseur will choose the right water for the right occasion, just like wine. Thus the sharp sparkle of Perrier from France or Apollinaris from West Germany makes a good aperitif; the lighter natural carbonation of France's Badoit, Italy's Ferrarelle and Belgium's Bru goes well with food; and the pure still waters of Evian, Vittel or Volvic from France, Panna from Italy or Font Vella from Spain are not only good table waters, but recommended for mixing baby formulas. Chic Frenchwomen, anxious to preserve their figures, keep a bottle of the more highly mineralized Contrexeville to hand as a diuretic, while Vichy Celestins may be preferred to ease the digestion.

These are all mineral waters in the classic European tradition. That is to say, they have all established a therapeutic reputation, which is acceptable by their governments, and they are bottled at source without treatment under very tight regulations overseen by their respective Ministries of Health. Within the European Economic Community (EEC) standard rules are now in force.

promoting mineral water throughout the western world. The names of Evian, Perrier and Vittel, the three big groups, crop up ceaselessly, providing technical know-how, buying up local waters or simply creating new markets almost from scratch. Go to Lebanon or Egypt and you find Vittel behind flourishing new waters. Vittel have also linked up in Japan with Marubeni, a leading Japanese trading company, both to market Vittel water there and to start developing European-style spas. In Spain and Italy, both Evian and Perrier own important sources. Perrier is also empire-building with a clutch of mineral waters in Brazil. As for the United States, the catalyst for the present boom was a Perrier campaign proving that water could actually be advertised from coast to coast. Besides encouraging a taste for their own waters in the United States, both Perrier and Vittel have also been buying up American springs to enable them to offer cheaper waters alongside their own 'chateau-bottled' brands.

Their success, of course, is due to the re-discovery of mineral water as <u>the</u> health drink by the modern generation that has turned to health foods. It has acquired a sporting image - almost like internal aerobics. We are concerned to cut down not just on alochol but on caffeine, sugar and sodium. Women are constantly advised to drink more, to avoid problems like cystitis, and here is a calorie-free way to do so. A good level of fluoride in daily water intake protects the teeth. And calcium, for strong bones, is needed not only by children, but also by post-menopausal women. The renewed interest in mineral waters has been accelerated for many of these reasons.

<u>But</u> it is worth noting that whereas the tradition in Europe was to drink waters for the minerals they <u>did</u> contain, here in Britain (and

especially in the US) it is exactly for what they do <u>not</u> contain. And while the medicinal benefits are by no means forgotten (especially in France, West Germany and Italy, where it is possible to visit spas under health insurance schemes), many of us here, I suspect, are wary of turning to these powerful weapons too often. But our young guide in Vichy was convinced that his recent recovery from a kidney infection had been achieved with less damage because he had taken a water cure and not used modern drugs. Mineral water is proved to be more effective than tap water in aiding elimination, and gentler than laxative pills. And a glass of mineral water containing natural bicarbonates with a meal seems to make more sense than drowning antacid tablets later. We are all increasingly interested in natural and alternative medicine.

Moreover, mineral water tastes so much pleasanter than water from the municipal tap. The knowledge in London that the local tap water, while safe, has already been recycled seven times, hardly encourages citizens to quaff great draughts. And occasionally the tang of chlorine in the tap water is all too pervasive. And just what do we mean by safe? Not very much is known about the effects of drinking heavily chlorinated water for a lifetime, but some of the studies undertaken so far are far from reassuring. Additionally, the rising level of nitrates in many British rivers, caused by liquid nitrate fertilisers used for high crop yields, is another reason for concern about ordinary tap water. Even without these potential health hazards, the problem facing water authorities is simple. They have to provide tap water to fulfil the disparate needs of drinking, cooking, bathing and doing the laundry. Yet a hard water is better for drinking, while a soft water is essential for a good lather.

So the way round for the consumer may be to wash in tap water, but get a drink out of a bottle. With local brands on supermarket shelves now competing with the more expensive 'chateau-bottled' imports, this alternative does not have to be costly. And as we travelled on our researches for The Good Water Guide, we came to agree with Paul Bordier, President of the French Mineral Water Association, who suggested to us in Paris: "Why not drink a litre of marvellous water a day? It costs half the price of your newspaper".

Well, the British are the world's greatest readers of newspapers. Are they set to become equally addicted to bottled waters? We should keep in mind, of course, that we started in this country from a very low base; the market was so tiny a decade or so ago that the only way it could go was up. Even by 1984 the British were only drinking in one year the quantity of mineral water that the French, Belgians or Germans drink in a week. Consumption has more than doubled since then, but the British intake is still a tiny splash; pushing towards 3 litres annually against France's 74 litres.

Reviewing today's bottled water market for this speech, compared with our research for The Good Water Guide four years ago, I was struck by three main points.

First, a significant shift is now taking place in the relationship between market share for carbonated and still waters. The British market of today - we must remember - and acknowledge - was largely created by Perrier in the 1970s with their scintillating 'Eau La La' and 'H2 Eau' slogans for their fizzy water. Since Perrier captured the high ground, the UK market is still primarily in sparkling waters which account for over 60 per cent (in terms of litres sold). But today, according to supermarket chains I have talked with recently, the biggest growth momentum is with still waters. The reason for this is that the market is in many ways maturing. Initially, sparkling mineral waters became a socially acceptable alternative to alcohol or other soft drinks at parties or dinner tables. Now, as the water buyer of one British supermarket chain told me, "People are using still water for tea or coffee and for mixing baby foods. They want a pure water that is nitrate and nitrite free." In short, people are now finding still bottled water a good alternative to tap water. And they are starting to buy it in larger units: more 2 and 5 litre bottles are appearing on supermarket shelves.

The trend was confirmed by another buyer for a major supermarket chain who told me, "In the Midlands and the North, a lot of growth is due to the poor taste of tap water. And in Scotland people are often worried about the heavy lead content because of old water pipes".

The resulting growth in natural (i.e. still) bottled water sales should not surprise us. In France, still water mineral waters account for over 80 per cent of the market, and only in West Germany, where there is a particular liking for very fizzy waters, is the British addiction to sparkling waters surpassed. An additional dimension is also developing through the introduction of water dispensers in hotels, offices and gyms (nothing new in America, if you think of all those Hollywood movies, but quite new here). As one analyst told me, "Water is going to be much more widely available in public premises as a service".

The second point that struck me is the widening regional appeal of bottled waters. The heartland of mineral water drinking remains London - over 28 per cent in 1988, but Lancashire and the Midlands are coming up fast, and growth is also taking place in the North East, Scotland and Wales. Mineral water drinking is going nationwide, and that in itself spells more consumption. Interestingly, they way ahead in the regions is being spearheaded by social drinking of sparkling waters in pubs and at parties, but in the long run that will pave the way for wider use of still waters too.

Thirdly, a sure sign that the water boom has momentum is the scramble by newcomers to get in. There is a proliferation of new, mainly British, waters. One report suggests there are 150 trying to get in on the act. One supermarket chain told me they are still offering at least two new waters a month. We are seeing, in fact, the development of a two-tier market: the imported 'chateau-bottled' waters, if you like, such as Perrier or Evian, Badoit, Volvic from France, Spa from Belgium, San Pellegrino from italy, Ramlosa from Sweden, Apollinaris and Gerolsteiner from West Germany, and the local 'plonk' from British springs. This is a natural development; selling water is getting very competitive. Freight costs inevitably burden an imported water (remember the water itself is free). So a local water can obviously compete. Look at Europe: in Italy or West Germany or Spain water is very much a regional thing; in Frankfurt you'll get one water, in Munich another. So major groups are buying up the best in British waters: Perrier has acquired Buxton, Spa from Belgium has launched Brecon.

The sheer range of waters now available in the UK market was underlined to us last autumn when my wife, Marueen, who wrote the book with me, participated in a 'water tasting' organised by Decanter, the wine magazine. They had assembled no less than 76 different brands (26 still, 37 sparkling and 13 flavoured). This included, incidentally, such waters from Ireland as Ballygowan Natural Irish Spring Water and Glenpatrick Spring Natural Pure Irish Water, both offering still and sparkling. Ballygowan also had waters with natural essence of lemon, lime and orange.

Additionally, there is now a British Natural Mineral Water Association, (BNMWA) with over a dozen members. And this year the first 'water bar' is likely to be opened in London, offering a wide range of bottled waters along with healthy snacks. The bar's owners are also proposing to launch door-to-door water deliveries and a 'water club' (rather like a wine club) which will offer selected waters each month. Very interestingly, they have been able to raise venture capital in the City of London for this.

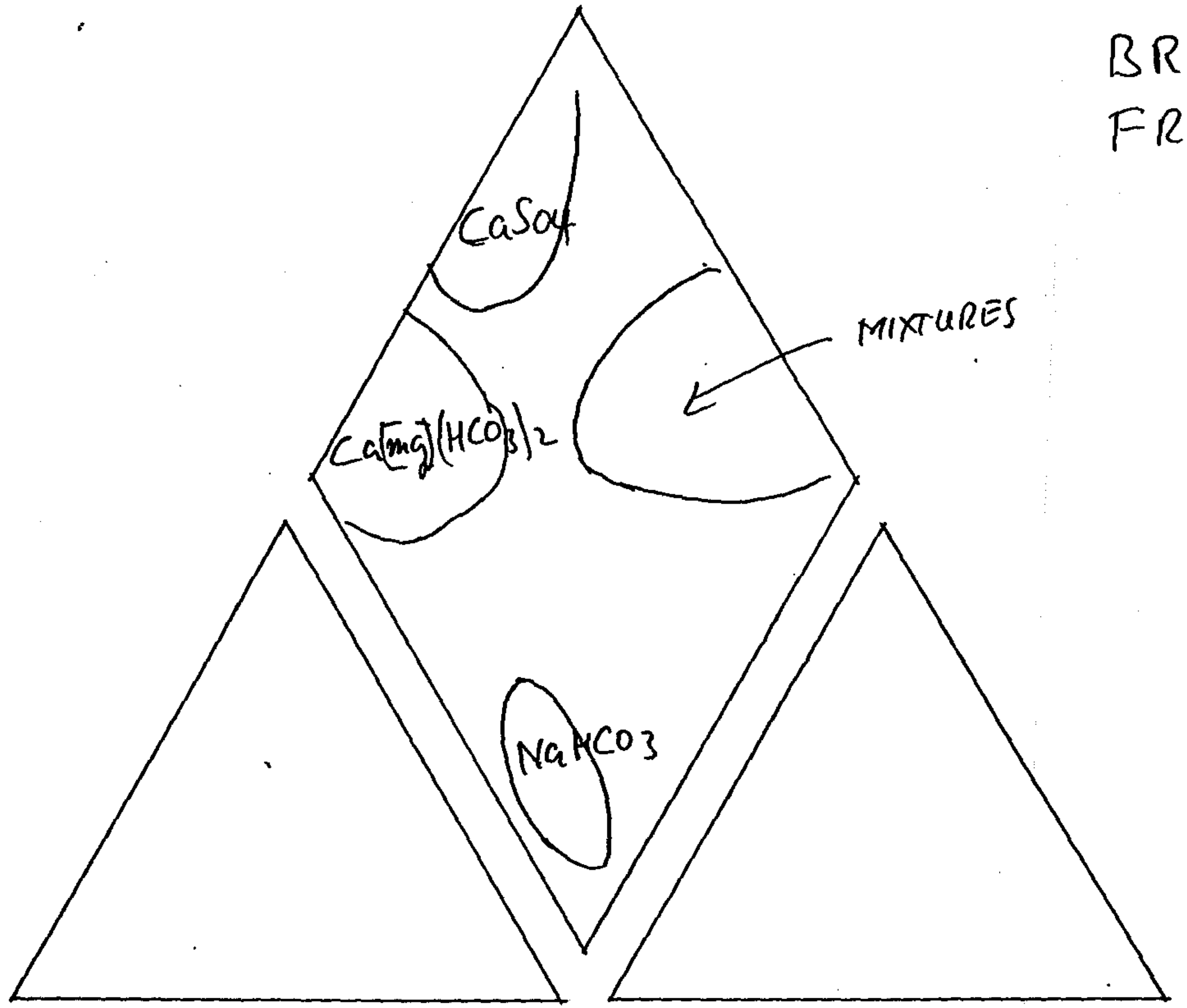
But it is our impression that these 'home grown waters', as it were, have a difficult time getting going; they are prey to takeovers by the big French, German or Belgian groups which have much more marketing expertise. Certainly most British waters (we have not yet been able to visit Irish) operate on a tiny scale compared to the vast factories of Evian, Vittel or Perrier; they are a truly cottage industry often operating in little better than a shed. Compare that with, say, Evian, which has seven railway tracks backing its factory, which alone bottles about 7 times as much water each year as the entire UK market consumes.

So although for the moment people often seem to be finding a handy spring in the back garden and try to market it under their own label, the really good quantity waters with a good flow are likely to fall prey to the bigger groups. A lot of the independents will be soaked up; although the original name may be retained. An added reason for these amalgamations is that the soft drinks companies are also pushing hard now to get a foothold in the water game. They do so for two reasons: first, obviously because it is a growing and profitable market, but also because concern about pollution of normal water supplies is going to lend cachet to soft drinks made with waters from springs; although they cannot actually be marketed as mineral waters, the label can proclaim that the lemonade is made from water from a Chiltern Spring, or a cola has water from a Scottish source. One interesting indication of this is that flavoured mineral waters (i.e. Perrier with a lime or lemon taste) are booming. In 1988 they accounted for 14 per cent of the sparkling water market, an increase of 43 per cent in a single year.

So, looking ahead, what is the prospect for water? The market is forecast to top the £200 million mark by 1990 - up 22-fold in the decade, with a total volume of perhaps 220 million litres, and reach perhaps 340 million litres worth £300 million in 1992.

It sounds spectacular, but let me leave you with this thought: that will still put annual consumption here at a mere splash of 4 litres per head; or one-eighteenth of the French, one fifth of the current American, and less than half the Dutch. There is thus no sign, if you will pardon the expression, of saturation. Indeed, may I sign off with *Time* magazine's summary of the vogue: "Welcome to the water generation".

BRGM REPORT
FRENCH TABLE
WATERS
SAMPLE = 34



Parameter \ Bottled Water	Perrier	Vittel		Evian*	Contrexeville*	Volvic	Vichy (Celestin)
		Grande Source	Hépar				
pH	6	7.2	7.0	7.6	7.4	7	
TDS mg/l	500	841	2580	322	2280	110	
TH (as $CaCO_3$) mg/l	367	653	1715	300	1500	51	
Calcium mg/l	140	202	505	77	472	10.4	100
Magnesium mg/l	4	36	110	26	78	6	9
Sodium mg/l	14	3.8	14	5	-	8	1200
Potassium mg/l	1	2	4	1	-	5.4	60
Bicarbonate mg/l	340	402	403	368	405	64	3000
Chloride mg/l	30	7.2	11	8	12	7.5	220
Sulphate mg/l	50	306	1479	10	480	6.7	130
Nitrate (as N) mg/l	nil	1.4	0.7	1.8	1.4	0.5	
Aquifer	Sand and gravel/limestone	Limestone	Sandstone	Sand and Gravel	Limestone	Basalt and Volcanic ash	

* Analysed by the State Laboratory
The remainder have been taken from Company literature or labels or the 'Good Water Guide' (Green and Green, 1985).

TABLE 1. Chemical Analyses of a number of French Bottled Waters.

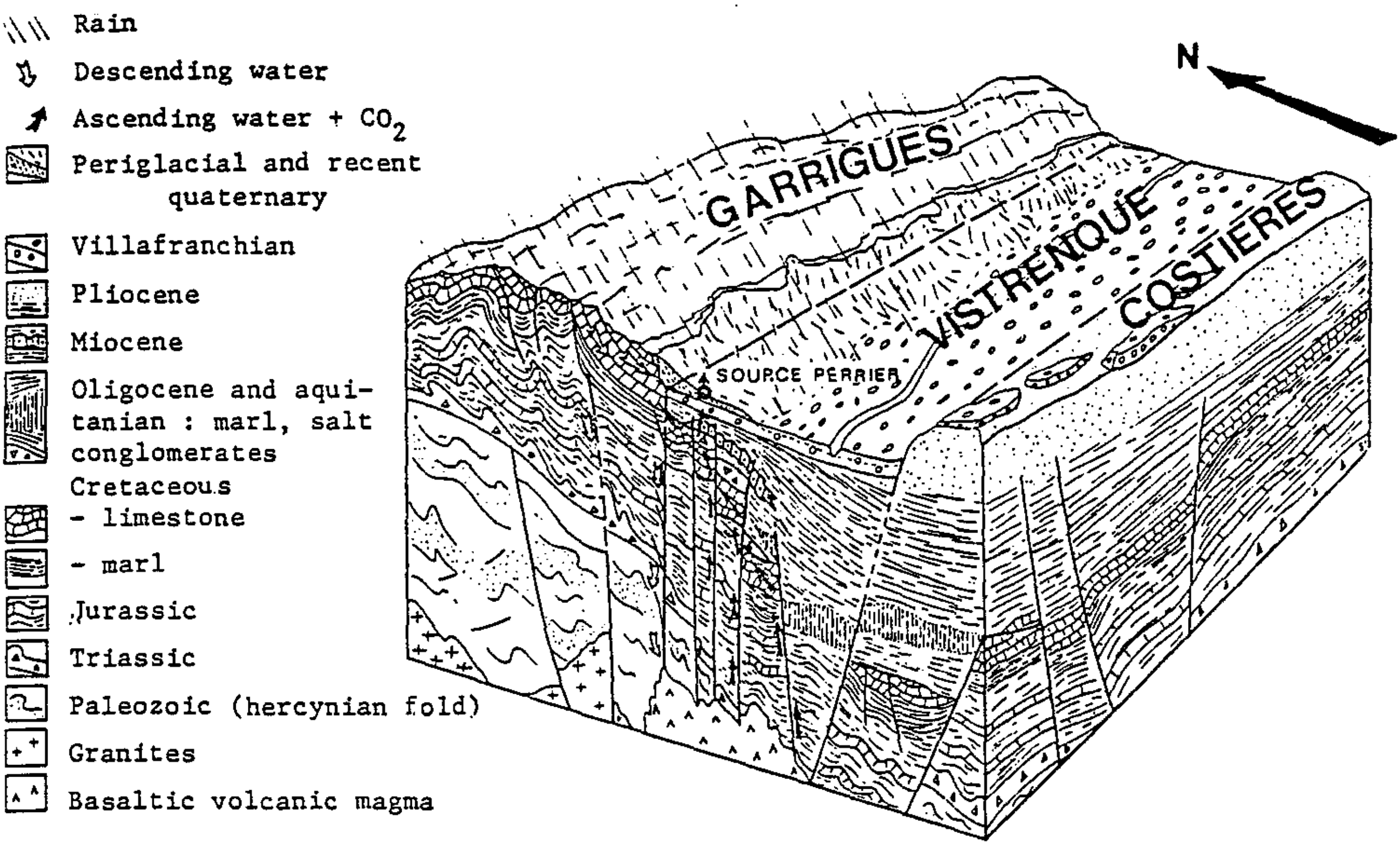


Figure 3

Fig. 3 - Schematic block diagramme of the geological and hydrogeological structure of the Perrier Spring and its surroundings.
The scales were only partially respected in order to make the schema clearer. Thus, the Villafranchian thickness has been largely exaggerated (thickness = 15 to 35 m) triassic is about - 4 Km below the Garrigues and the volcanic intrusions are between - 5 and - 8 Km. The central compartment of the graben (normally beneath the Costière) has been slightly displaced toward the North-West.
The Vauvert fault, interpreted as a re-play of a deep accident in the base might correspond to a fault resulting from the settling of thick oligomiopliocenic layers. For reasons of simplification, the miocene and the villafranchian formation of the compartment to the north of Nîmes fault have not been represented. The synsedimentary play in the majority of the faults will be noted.

Fig. 4 - Intense fracturation which transversally cuts through the Nîmes fault system perpendicular to the Perrier Spring, according to a survey conducted by R. Dominici (1966) in the VERGEZE railroad stretch (above) and the Uchaud railroad stretch (below).

Fig. 5 - Synthetic cross-section (without scale) of the statigraphic column of the formations of the Vistrenque graben, perpendicular to les Bouillens.
C = periglacial slope ; Q = middle and recent quaternary complex ; V = villafranchian ; A = intermediate, impermeable clay ; P = Pliocene, plaisancian blue marl, with sandy precedent ; M = Sandstone, sand or reef-miocene (bryozoan limestone reefs (R) ; O = oligocene conglomerate ; NC = folded and fractured neocomian limestone ; Nm = neocomian marly base ; L = deposit or erosion lagoons. The horizontal arrows indicate the aquiferous levels ; G = circulation or CO_2 storage zones.

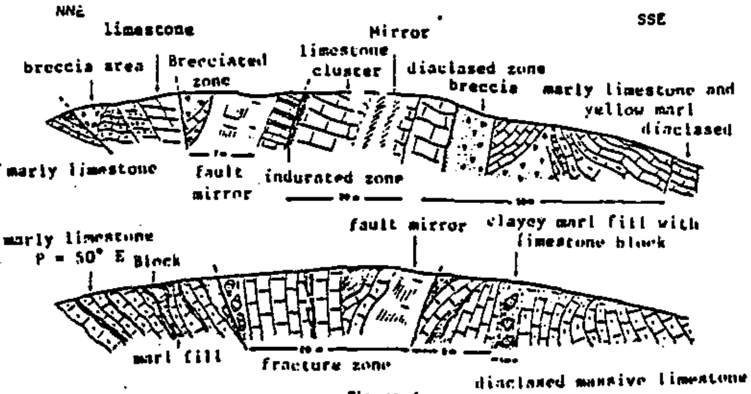


Figure 4

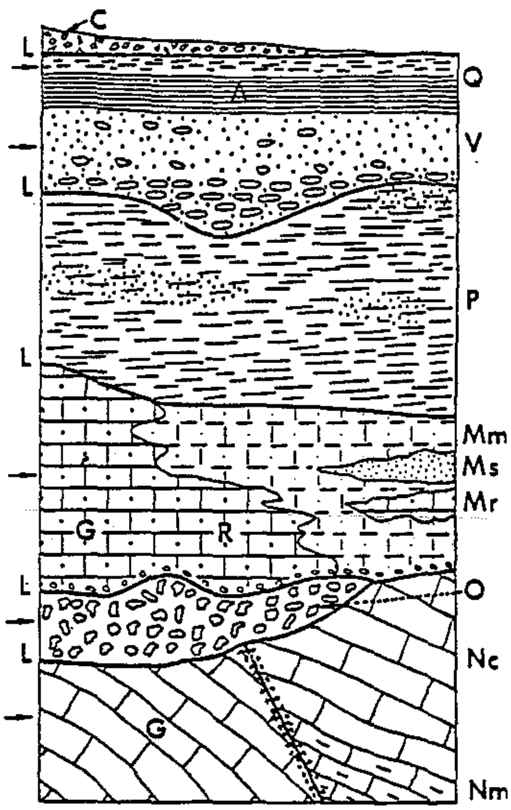


Figure 5

FIGURE A

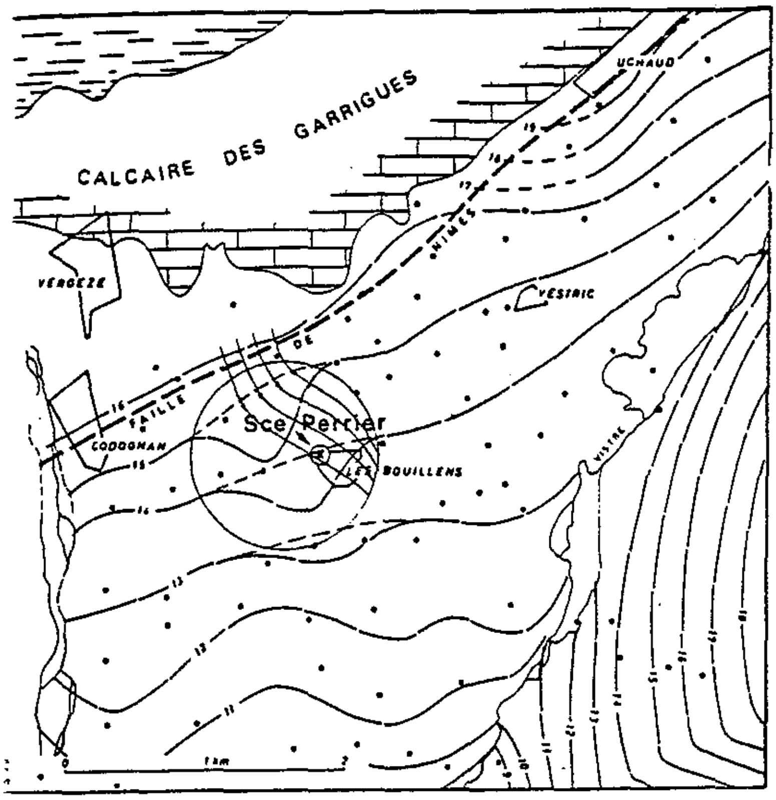


FIGURE 6

Isopiezes of the villafranchian paleo-alluvial aquifer (High waters, 3-14 April 1964, based on the work of J. Coudray, 1965) in the PERRIER SPRING AREA.

The following will be noted :

a) - The form of the isopiezes resulting essentially from the existence of feeding from the north boundary of the Nîmes fault and from a drainage by the Vistre ;

b) - The deformation of these lines near the Spring (*in the circle*), due to the subterranian advent, in this spot, of the second component (c. karstic) of "Perrier water" ;

c) - The artesian aspect of the spring during this period (despite the pumping then taking place) ; the isopiezes lines were then above the surface of the soil (+ 14.20 m, headspring at + 11.50 m), perpendicular to Les Bouillens.

Black dots = points of piezo-metric measurements.

FIGURE 7

...rrier spring catchment. Crossed formations, and scheme of separate catchment drillings for water and carbonic gas.

...gend : S.A.O. = original artesian spring of the Bouillens pool (headspring shown at + 11.50)

I.E. = Bottling installation

F = Open fault

C_1 to C_3 = "Perrier Water" components

...rossed formations : (on the scale down to - 28 m)

: Vegetal earth 0 to - 0.50
: Sandy debris with limestone splinters) - 0.50
: Gravel-like clays) to - 2.50

} soil + middle and recent Quaternary period.

: Compact clay (- 2.5 to - 5 m : impermeable roof of the confined aquifer)
: Sand and more or less clayey gravel (- 5 to - 7 m)
: Fine to thick siliceous, gravel and pebble sands (- 7 to - 19.5)
: Predominantly gravel and large pebbles and siliceous sand (- 19.5 to - 22.1) (mixture zone)
: Plaisancian blue marl (villafranchian wall of the aquifer)
: Bryozoan limestone reefs (Burdigalian - Miocene period) ; in the - 16.3 m (drilling 63) and - 32 m (drilling 63 bis) and - 400 m in the tiers of the graben.

O : Oligocene conglomerates.

I : Folded and fractured neocomian limestone

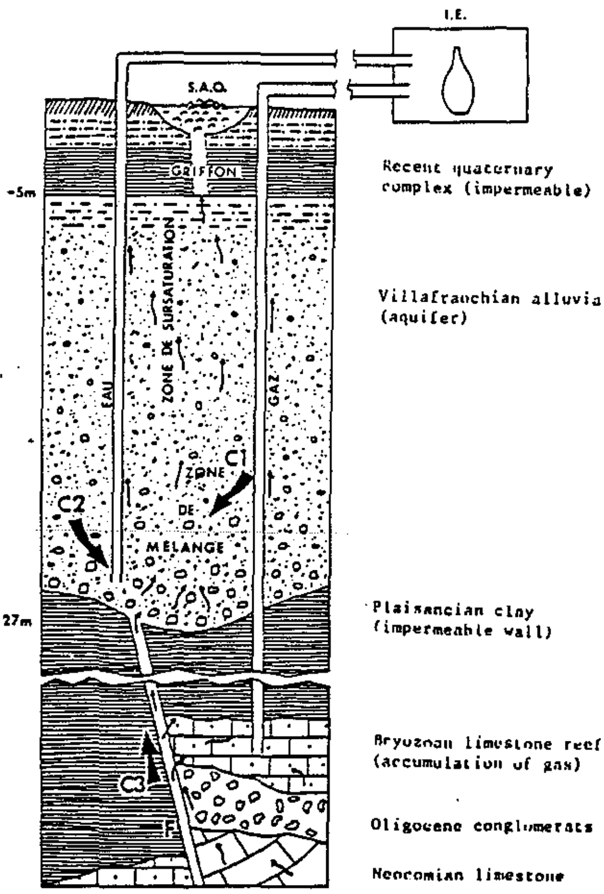


FIGURE B

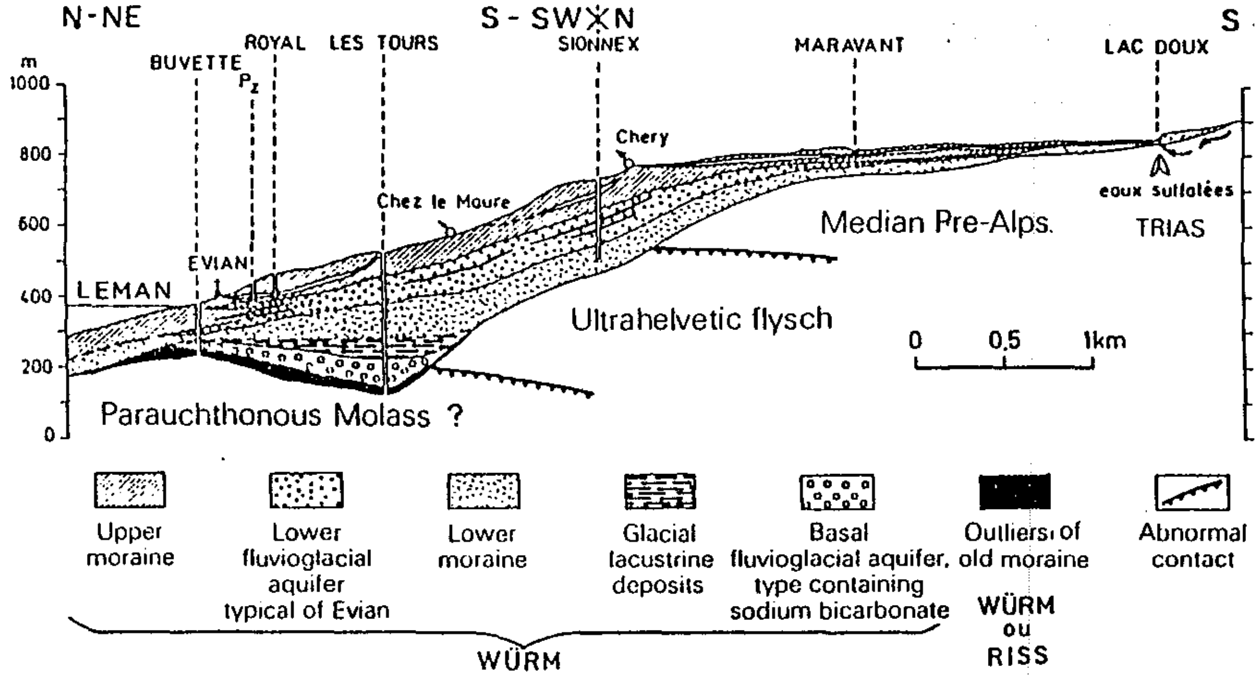


Fig. C - SECTION THROUGH THE QUATERNARY OF THE EVIAN HILLSIDE

GROUNDWATER AS THE SOURCE OF BOTTLED WATERS

Eugene P. Daly - Geological Survey

Throughout the world groundwaters from a wide range of hydrogeological environments have been developed as the raw material for a bottled water. Hence the chemistries of these waters are quite variable with many waters being a mixture of the main types and no two waters being exactly the same.

A review of the waters mentioned in the 'Good Water Guide' (Green and Green, 1985) and the bottled water labels etc. in the Geological Survey files shows that most of the waters on the European and North American markets fall into a few types. Calcium/magnesium bicarbonate waters with total dissolved solids up to 600mg/l are the most common. Other water types found in significant numbers are:-

(1) bicarbonate waters with substantial concentrations of two or three cations and high mineralization (TDS of 600-2,000 mg/l).

(2) sodium bicarbonate waters frequently with solids in excess of 2,000 mg/l.

(3) sulphate waters frequently with substantial bicarbonate, a variety of cations and high TDS (600-2,000 mg/l).

Most of these water types are available in Ireland although as stated earlier they generally have low mineralization owing to the particular hydrogeological environments here.

Some examples of where the common water types are available in Ireland in significant quantities (i.e. > 500 m^3/d) are listed below.

(a) Waters with low TDS (< 200 mg/l). The Ordovician Volcanics in Wexford and Waterford.

(b) Calcium/magnesium bicarbonate waters with TDS up to 600 mg/l. Widely available in limestone, dolomite, sandstone and sand and gravel aquifers. Some of the limestone aquifers may be vulnerable to pollution.

(c) Calcium sulphate waters with bicarbonate and high TDS (i.e. 600-1500 mg/l). These waters are available from the limestones and sandstones of the Cavan, Fermanagh, Monaghan and Armagh lowlands.

(d) Sodium bicarbonate waters with solids up to 600 mg/l. These are available in the confined parts of many aquifers (e.g. Castlecomer Plateau). Locating this type of water is more difficult.

The only other types of groundwater used in bottled waters and not available here are the very highly mineralized sodium bicarbonate and sodium chloride waters. As our hydrogeological knowledge (particularly at depth i.e. > 100m) improves we probably will discover some of the more unusual types of groundwater.

The hydrogeological details of two popular French bottled waters are given below.

Source Perrier

This note is a summary of the paper on the "Geology and Hydrogeology of the Perrier Spring "presented by Prof. J.V. Avias to a meeting in France in 1980.

Source Perrier is located, amongst the Vineyards, in a small plain in the south-east of France. It is the name given to the spring (temperature 15.4°C) which flowed into a large pool (Les Bouillens). The water coming into the pool was supersaturated with CO_2 which gave it a "boiling" effect and forced it to overflow at times. The pool has been covered over and the water and gas are now collected through boreholes.

The Vistrenque plain is underlain by a sequence of Triassic to recent sediments. Basement in the region consists of folded Palaeozoic rocks, granites and basalts (Figure A). These strata are part of a Graben structure (Oligocene). Volcanic activity along the Nimes fault accompanied the development of this structure.

The principal water bearing horizons are the Villafranchian sands and gravels (Pleistocene?) and the Cretaceous Limestones (karstic).

The upper aquifer is confined by a thin clay layer on top and thick blue marls underneath.

The water in 'Source Perrier' is said to have resulted from the natural mixing underground of three components:

(1) the water from the sand and gravel aquifer - the main component.

(2) the waters from the Cretaceous limestones which are thought to flow up along the Nimes fault. These strata outcrop on Nimes Garrigues (upland).

(3) a small volume of more highly mineralised, hot water with a high CO_2 content. Avias (1980) suggests that the heat and CO_2 are of volcanic origin and that it is the heat that circulates the groundwater in the fracture system of the graben. The gas accumulates in the Miocene limestones (high porosity) where it is trapped by the overlying

Pliocene marls. At the site of "Source Perrier" these marls are quite thin allowing this CO_2 charged water to flow into the sand and gravel aquifer and mix with the other two components.

Nowadays the water and gas are collected separately and mixed in the bottle (Figure B). Perrier is a calcium bicarbonate water with CO_2 (Table I).

The two contributing aquifers are well protected. The Nimes Garrigue where the Cretaceous limestones outcrop are forested and the Villafranchian sands and gravels are protected by the overlying clays and the sand and clayey gravel at the top of the unit.

Evian mineral water sources

This is a short summary of the paper by B. Blavoux on "The Geology of the Evian mineral water sources".

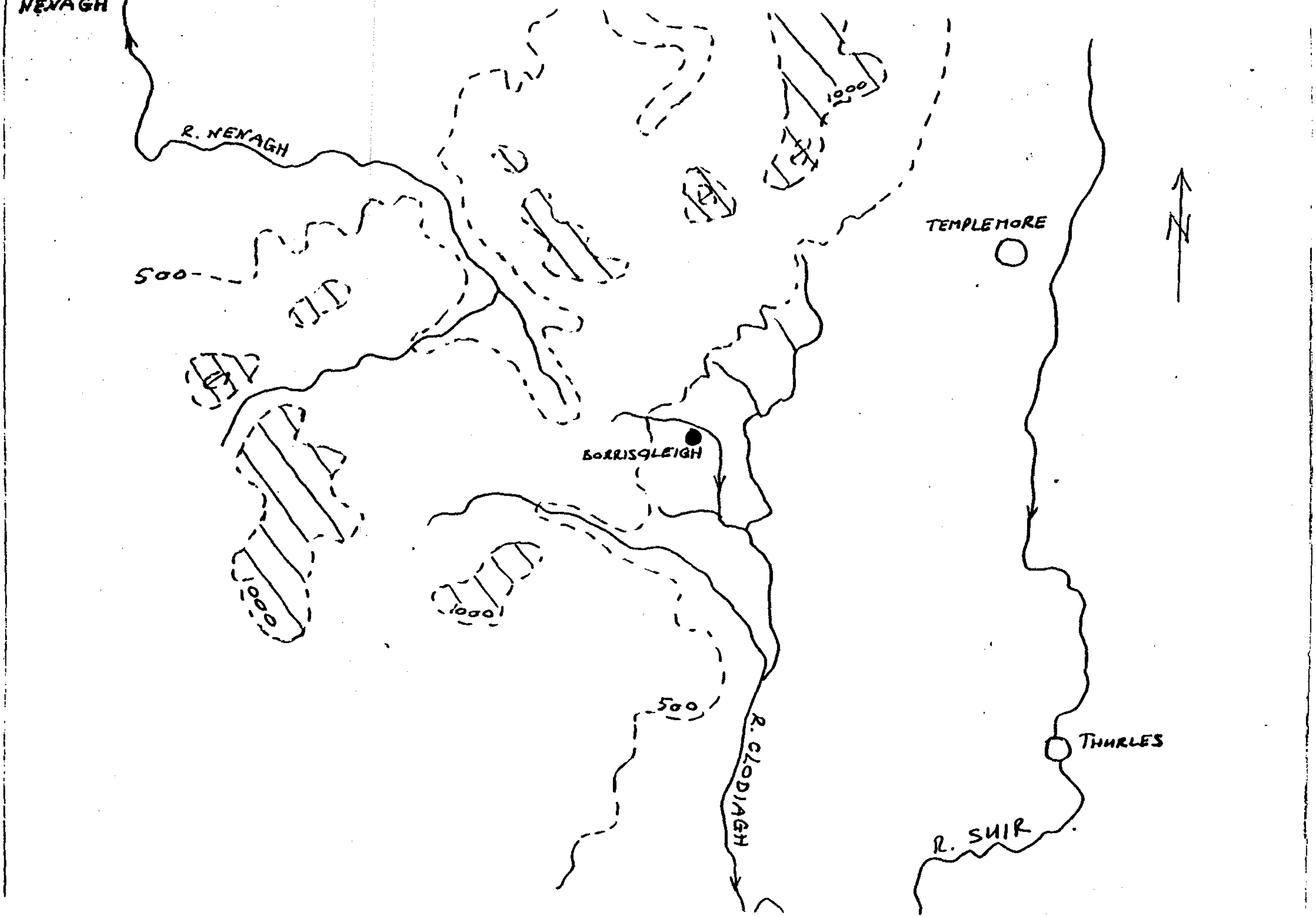
The town of Evian is situated on the southern shore of Lake Geneva in eastern France. A number of springs, one of which is bottled (Cachet Spring), emerge in a small area at the base of the Vinzier Plateau which are part of the foothills of the Alps.

The Triassic rocks (calcareous) of the Vinzier plateau have been thrust over the older strata beneath them. On the slopes of the plateau these rocks have been overlain by a succession of Quaternary deposits which are about 400m thick just south of Evian (Figure C). These strata consist of at least two extensive lenses of fluvioglacial sands and gravels interbedded with morainic tills.

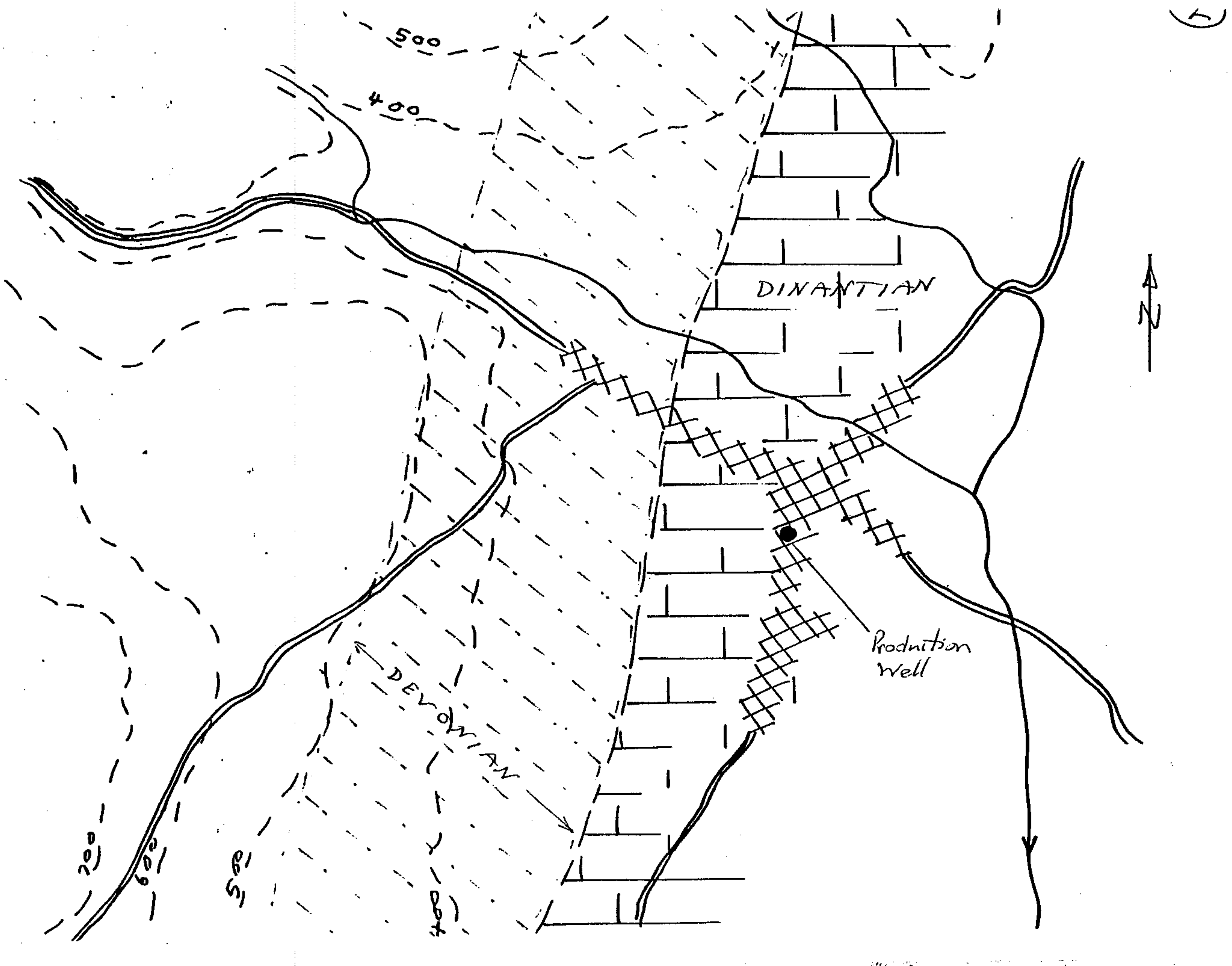
The upper sand and gravel is a confined aquifer and is the source for the Evian mineral water. Hydrochemical investigations have shown that the aquifer is recharged on top of the plateau through the upper till where it is less than 10m thick. The residence time in the aquifer is thought to be 20-40 years. The aquifer is being tapped by two 6m sumps at the end of a 66m horizontal gallery. The combined flow of all the springs is around 3,700 m^3/d and the company have a licence to abstract 2,300 m^3/d through their gallery with an artesian head of 4.5 kg/cm^2 (64 p.s.i.).

Evian is a calcium/magnesium bicarbonate water with a relatively low level of dissolved solids. The lower aquifer at this location (Figure C) contains sodium bicarbonate type water.

The water in this aquifer is well protected by the overlying morainic till.



NENAGH
R. NENAGH
500
1000
1000
1000
1000
BORRISOLEIGH
500
R. CLODIAGH
N
TEMPLEMORE
THURLES
R. SUIR



1
N
500
400
DINANTIAN
DEVONIAN
Production Well
400
500
600
700

TIPPERARY NATURAL MINERAL WATER, GEOLOGICAL INFLUENCES AND CHEMICAL CHARACTERISTICS

Stephen Peel, Minerex Ltd, Dublin

Location & Geological Setting

The source of Tipperary Natural Mineral Water is in Borrisoleigh on the southeastern flank of the mountainous area that includes Keeper Hill and Devilsbit Mountain; southwest of the Slieve Bloom Mountains. The area is an inlier in which Lower Palaeozoic (Silurian) rocks crop-out. Outcrops of Devonian formations surround the Silurian rocks and these are overlain on lower ground by Lower Carboniferous (Dinantian) formations. Bedding planes within the Dinantian at Borrisoleigh dip at shallow angles to the southeast. No major structural features have been reported in the area but the existence of a NW-SE fault passing through the village has been postulated.

Rock Types

The Silurian rocks consist of sandstones and shales that are generally folded and cleaved. The Devonian rocks are "Old Red Sandstone" comprising a pale Basal Sandstone underlain by Red Beds, described as a sandstone and siltstone sequence. The Dinantian rocks comprise mainly dark argillaceous limestones with thin shale horizons. These are overlain by a variable thickness of till.

Groundwater

Yields from boreholes in and around the village have been found to be moderate to poor and in recent times to be inadequate. This is because the limestones are largely impermeable in the locality with water being obtained only near their base or in the underlying Devonian rocks. A good new source was found on lower ground to the southeast of the village where the limestone was found to be permeable.

The Tipperary Source

The source for the natural mineral water is a borehole that penetrates some 76 metres of impermeable limestones and extends to 85 metres into sandstones. The groundwater rises close to surface under artesian pressure and has a safe yield of 200 m^3/day for a drawdown of 30 metres. It has a temperature of 12^{o}C.

Water Quality

Inorganic Chemical

Repeated analyses of the water for major anions and cations show that the quality of the water is consistent. The hardness of the water is 175 ± 5 mg/l ($CaCO_3$); less than half that of the water from the limestone aquifer to the SE of the village. A notable characteristic is the high potassium concentration of 15 to 17 mg/l which is attributed to the sandstone from which the water flows. Trace element concentrations are all at low levels.

Organic Chemical

The water was analysed for a number of organic chemicals, including halogen compounds, in order that the water might be assessed for certification for sale in the State of New York and all concentrations were found to be within the limits set.

Microbiological

Total bacteria counts are determined daily and are currently in single figures. No coliforms, anaerobes, streptococci or pseudomonas have been detected in the water.

Organoleptic

The water has consistently low colour, turbidity and odour.

Freedom from Pollution

The area of Silurian and Devonian outcrop up-dip from the source was studied and assessed with regard to land use and the possibility of aquifer contamination. Satisfied that the groundwater was not subject to contamination, natural mineral water status under EEC Directive 80/777/EEC was applied for and granted in 1987.

TIPPERARY
NATURAL MINERAL WATER

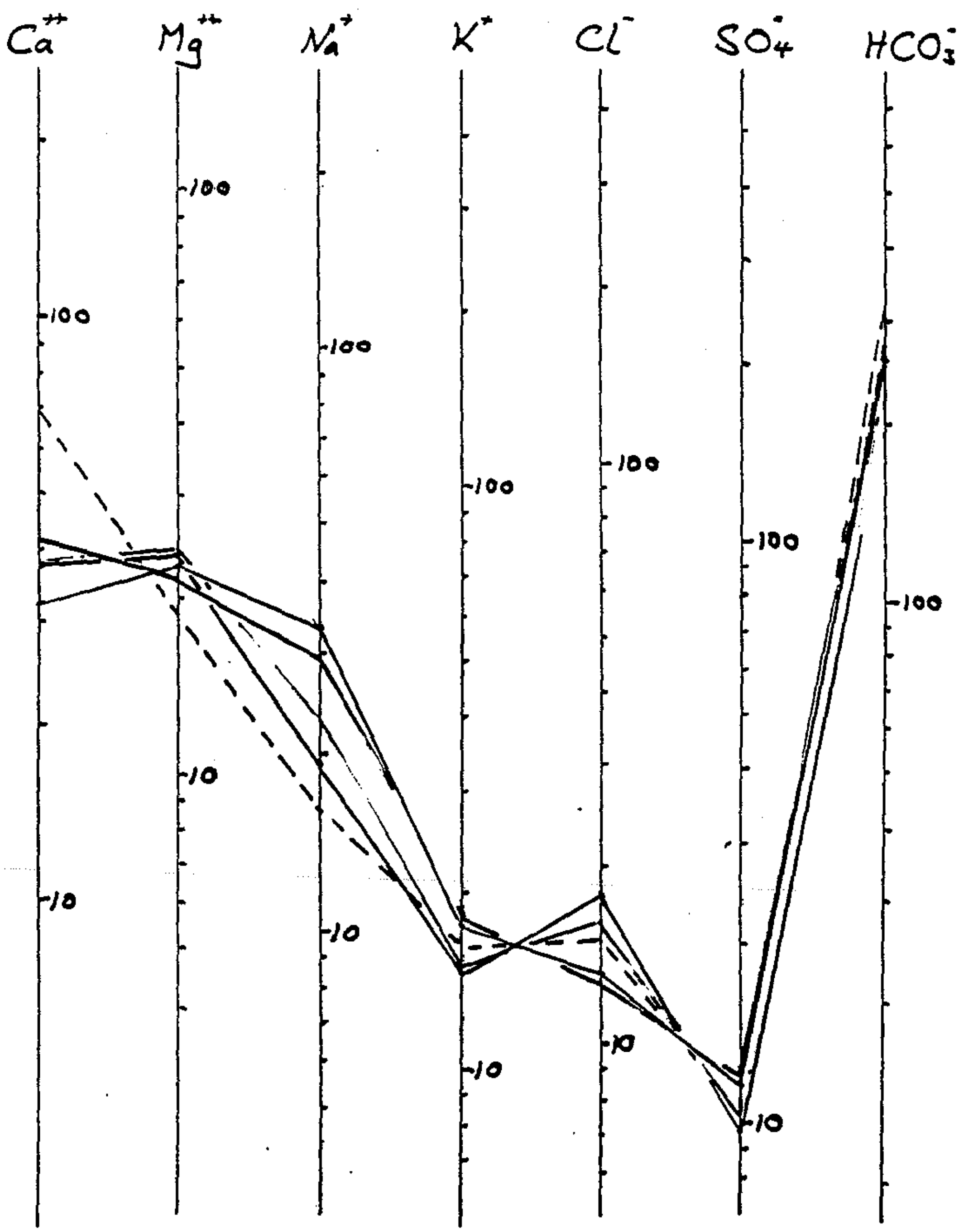
TURBIDITY	4
ODOUR	< 1
COLOUR	< 5 °H
TEMPERATURE	11.4 – 11.8 °C
pH	7.65 – 7.9
TOTAL HARDNESS	166 – 185 mg/l as $CaCO_3$
TOTAL ALKALINITY	235–250 mg/l as $CaCO_3$
T. D. S.	280 mg/l

TIPPERARY NATURAL MINERAL WATER

INORGANIC CHEMICAL

	mg/l	
CALCIUM	38	
MAGNESIUM	24	
SODIUM	19	
POTASSIUM	15	
IRON	0.1	
MANGANESE	0.02	
ALUMINIUM	0.02	
LEAD	< 0.005	
ZINC	< 0.02	
COPPER	< 0.002	
MERCURY	< 0.001	
BICARBONATE	280	(as $CaCO_3$)
SULPHATE	11	
CHLORIDE	16	
FLUORIDE	0.2	
NITRATE	2	
AMMONIUM	0.1	
PHENOLS	<0.1	

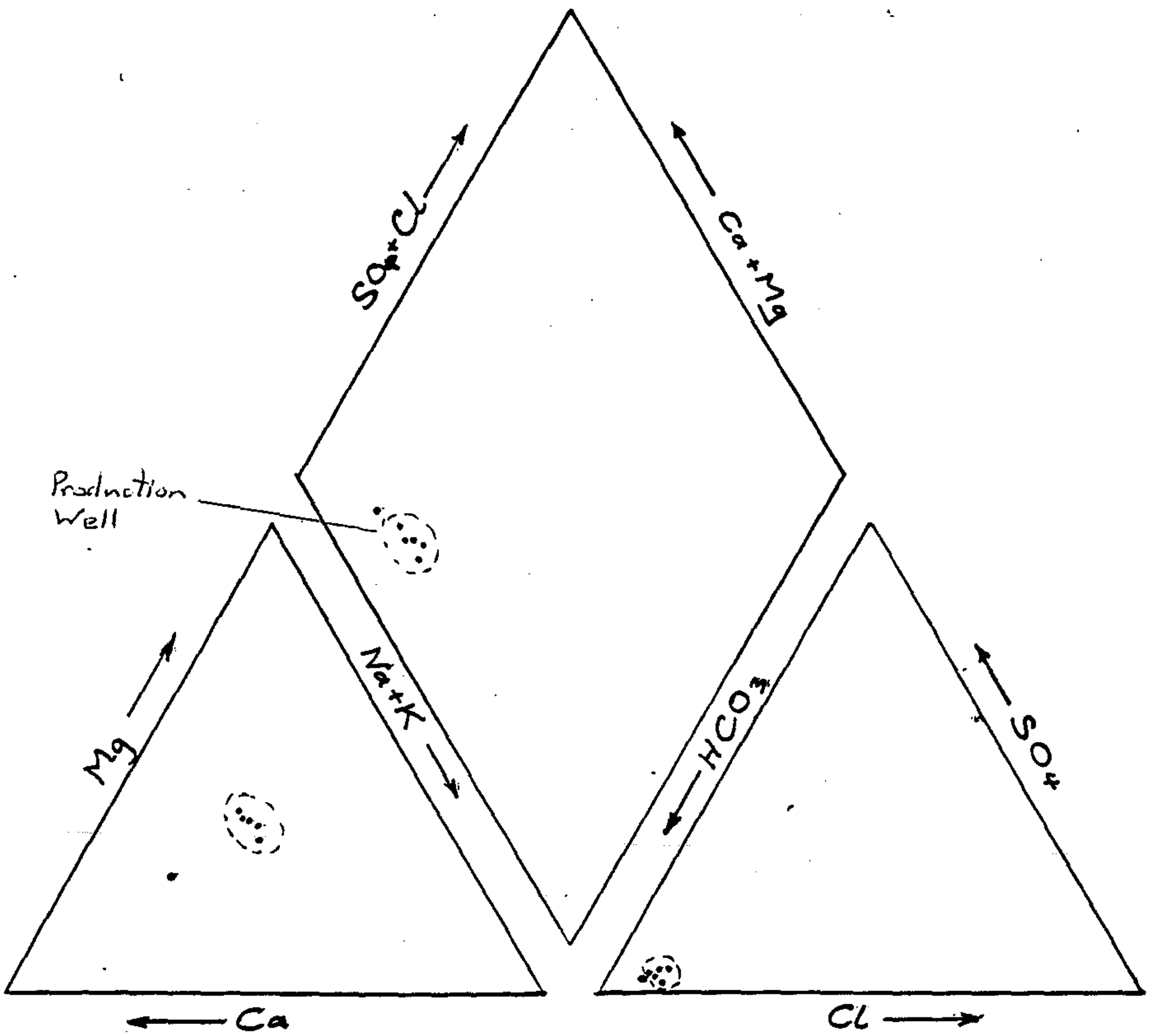
TIPPERARY NATURAL MINERAL WATER



MILLIGRAMMES PER LITRE

TIPPERARY NATURAL MINERAL WATER

TRILINEAR DIAGRAM



INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS

IRISH GROUP

9th ANNUAL GROUNDWATER SEMINAR, 1989

****

A BOTTLED WATER FROM BELFAST

by PETER BENNETT

Hydrogeological & Environmental Services Limited,

387 Lisburn Road,

Belfast.

In the late nineteenth century and early decades of this century Belfast was apparently a thriving centre for the production of 'Mineral Waters' which were exported on a world-wide basis. Relatively little WATER per se was bottled for sale but a range of carbonated soft drinks was produced, based on borehole water taken from the sandstone aquifers underlying the city. At one stage there were at least ten firms engaged in this business, each with its own borehole supplies. One of these firms, Ross's, eventually moved from near the city centre to Ravenhill Avenue and, in 1976, constructed a new water borehole to a total depth of 87.2m with a yield of 9,000 gallons per hour. This water was mainly used for soft drinks but was also bottled (carbonated) and distributed in Europe, the Middle East, and North America.

Following the EEC Directive on Natural Mineral Waters of 1980 which was implemented in Northern Ireland by Regulations in 1985 official recognition of the water was sought on the basis of the required hydrogeological assessment, chemical and microbiological analyses.

This water has a high mineral content, the sulphate content being particularly high, and the microbiological quality is excellent. Although it is located in an industrial area of a large city the aquifer is protected from contamination by overlying strata (see diagram) providing a good example of a source which could meet the regulations despite apparently adverse surface conditions.

Early in 1986 all the relevant evidence had been submitted to the Environmental Health Department of Belfast City Council and official recognition as a Natural Mineral Water was imminent, but Ross's were bought over and closed down by another large soft drinks manufacturer.

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Consultants in the geological & environmental sciences

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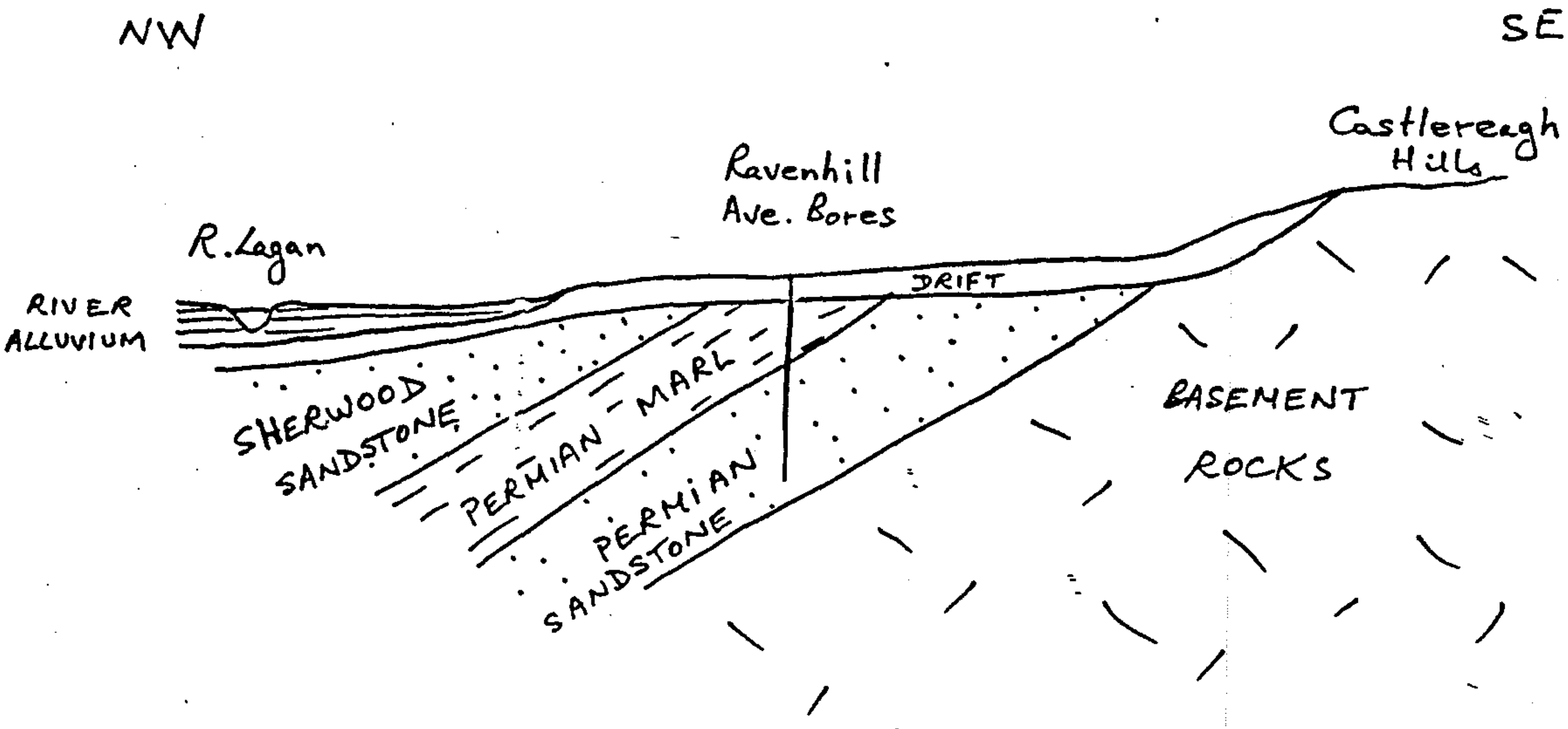
Diagrammatic Geological Section



TIPPERARY N. M. W.

BACTERIOLOGICAL ANALYSES

	TIPPERARY WATER	E.E.C. G.L.
TOTAL COUNT @ 37°C	2	5
TOTAL COUNT @ 22°C	5	20
TOTAL COLIFORM	N.D.	
+ E COLI	N.D.	
SULPHITE-REDUCING ANAEROBES	N.D.	
FAECAL STREP.	N.D.	
PSEUDOMONA AEROGINOSA	N.D.	

N.D. = NOT DETECTED

TIPPERARY N. M. W.

ORGANIC CHEMICAL ANALYSES
(MILLIGRAMMES PER LITRE)

	TIPPERARY	NEW YORK STATE	SOLUBILITY
ENDRIN	<0.0002	0.0002	0.2
LINDANE	<0.0004	0.004	7
METHOXYCHLOR	<0.01	0.1	0.1
TOXAPHENE	<0.005	0.005	3
2,4-D	<0.005	0.1	620
2,4,5-TP	<0.005	0.01	
TOTAL TRIHALOMETHANE	<0.08	0.1	

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Co. Tipperary
Ireland
Telephone (052) 22663
Fax (052) 22330

PRESENTATION

BY

BRIAN DUFFY MANAGING DIRECTOR GLENPATRICK SPRING WATER CO.,

TO

THE INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS

AUTHOR: BRIAN DUFFY (MANAGING DIRECTOR)

Chairman, Ladies and Gentlemen,

What an honour it is for a young growing Company like ours Glenpatrick Spring Water Company to be invited to address the Irish Group of the International Association of Hydrogeologists on the creation of Glenpatrick:

THE PRODUCT:

THE COMPANY:

THE ENVIRONS OF GLENPATRICK:

THE MARKETS IN WHICH WE OPERATE:

The origins of Glenpatrick began on a dark January afternoon in 1985 when, in the course of bottling soft drinks, we discovered a light deposit in some of our finished product.

At that time we were purchasing all our water supplies from Clonmel Corporation. After exhaustive tests we alerted them to our problem, suggesting that there might

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be some irregularity in portion of our town's supply. It transpired that the side of one of the streams in the Commeragh mountains had collapsed, and that a light alluvial deposit had entered the system.

We decided then to see if there was a water supply on our premises, a two acre site on the outskirts of Clonmel, and nestling in the gentle countryside surrounded by the Commerach mountains on the south and Slievenamon - famed in song and story - on the North East.

Our local National School Master, with a reputation as a water Diviner, walked our site encountered many twitching twigs and fullfilled the brief of locating the most plentiful and purest water supply identified then and developed since and now the Glenpatrick Spring for us. There followed the successful drilling and bringing the water overground when the necessary chemical and mineral biological testing began. This revealed a pure water, rich in calcium, low in salt, and with an ideal PH value with a delightfully refreshing and invigorating taste. At that stage the decision was made to carbonate this natural resource more gently than other products.

The surrounding countryside rich in calcium from famed limestone veins that transgress the earth under the world renownd Golden Vale clearly enrich this treasured resource. The beautiful appealing landscape in the neighbouring St. Patrick's Well, close to the environs of the Glenpatrick plant enhances the imageary

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of this most natural of Irish products.

When we came to name our product, a short list was assembled, some based on the townslands surrounding this historic and progressive country town, synonomous with all that is good about Ireland and so strongly perceived at home and abroad. With this background, the romantic townland of Glenpatrick an area of some 2,000 acres nestling high in the Commeragh mountains and the source of much of the surface water for Clonmel, became a natural choice. This lovely picturesque hamlet, renowned for its unpolluted rambling pastures and woodlands situated at the foothill of the historic Knockanaffron was the chosen site for much of filming of Barry Linden in 1973.

Glenpatrick became a commercial reality when launced on the Irish market in April '86. Our philosophy was to search out/in national and international markets selective niches where our product, our packaging and our presentation were clearly identified with all the goodness perceived of Ireland - a clear environ, free from acid rain and without vast commercial exploitation of our rolling green countrysides and Irish pastures, renowned worldwide qualities that have played such a part in establishing our bloodstock and agricultural products in the eyes of discerning international consumers.

There followed the successful launch of Glenpatrick in July '86 in the New York metropolitan area, with listings in such prestigeous outlets as Macy's, Shoprite, Sloans. October of the same year saw the launch of Glenpatrick into the U.K. market, a base from which considerable development has taken place, principally in the South East and Midlands. Other markets in Canada, Japan, Cyprus, France, The Canary Islands and Denmark followed. During this time the Company was actively working with the Institute of Industrial Research and Standards to gain recognition as a natural mineral water. These workings came to fruition in January '89 when the Company was proud to receive this auspicious reward, an area where a lot of pioneering work had been done by my colleague and friend Pat Cooney. With these developments Glenpatrick was submitted for testing research with C.E.R.V.A.C. Department of the University of Marseille for suitibility on the French market, and also with the Fresinius Institute in Germany, where the valued endorsement of these renowned centres is a decided marketing plus. We are particularly proud that Glenpatrick has been chosen by Marks and Spencer as a Supplier to their Irish and European stores, and this endorsement underlines the high level of quality control and plant hygiene to which we constantly aspire.

So much for where Glenpatrick has come from. Now let us look to where we see Glenpatrick Spring Water moving in the national and international market places.

THE IRISH MARKET:

The market for mineral water in Ireland has expanded very rapidly from a position where it was totally supplied by imports up to 1983. Since then the market has

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exploded with the extra volumnes being supplied from domestic producers. The Irish scene could therefore be summarised as a young developing market with further potential for double digit volumne growth for the next 3 to 5 years. The principal contributors to this exciting trend have been:-

(1) The increased consumer awareness of the quality of bottled water versus tap water:

(2) The increased consumer concern with health and fitness:

(3) The anti-alcohol lobby/trends together with the increased activity in the driving with alcohol campaign.

(4) The increased shelf space given over in supermarkets to water, and the increased advertising, P.R. and promotional activities undertaken by the main players in the industry.

In over-all terms, the present consumption per head is as follows:

Ireland	3 litres per annum
U.K.	3 litres per annum
Europe	up to 50 litres per annum

THE U.K. MARKET:

For all the same reasons, the U.K. market is projected to grow rapidly. Analysts

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and sources within the industry have predicted a growth rate of 300% over the next threeee years. The bulk of the industry within the U.K. is located within the London, South East and Home Counties area. It will be our intention to target on selected ethnic niches where associations and perceptions of the natural advantages of Ireland are more important to the discerning consumer.

EUROPE:

With an annual consumption of 35/50 litres per head and all the potential negatives of hyper industrial development in domestic local supplies, the presence of acid rain and the potential risks of further Chyernobles again the natural advantages of a mineral water from Ireland are significant. Within such a huge population spread and in general terms a market more highly developed and affluent than Ireland, there are significant and worthwhile niches. Here again the health aspect and low sodium content are decided market advantages, and these, together with good committed distribution partners, are more worthwhile assets in preparing a strategic approach for success pre and post 1992.

Ladies and Gentlemen, I hope that you have enjoyed this brief history of Glenpatrick to the same extent that I have felt in presenting it to you.

WATERQUALITY FOR FARMED SALMONIDS

GERARD MORGAN
AQUATIC SERVICES UNIT
UCC

Introduction

Over the past six or seven years, the production of farmed salmonids in Ireland, particularly Atlantic salmon (*Salmo salar*), has increased enormously. During that period and especially in recent years, the identification of sites with water supplies of suitable quality for the culture of salmonids, has been one of the priority activities of the industry. This has not always been an easy task, however, because of the very exacting requirements of these fish, particularly salmon. Many years of research have shown that a very wide range of physico/chemical constituents, occurring naturally and introduced because of mans activities, have an important bearing on the suitability of a water source for wild and farmed fish. In the present paper, only those constituents considered relevant in the Irish context are discussed. These include, temperature, pH, suspended solids, dissolved oxygen, ammonia and metals.

This paper relies heavily on the extensive literature reviews of EIFAC (European Inland Fisheries Commission) (Alabaster and Lloyd, 1982) upon which the EEC directive on the quality of freshwater fisheries (78/659/EEC) is based.

Temperature

Temperature is one of the most important features of waterquality as it relates to fish culture. Not only because of its influence on the survival and growth of all stages of a fishes life cycle, but also because of its influence on a wide range of chemicals in water e.g. dissolved, oxygen, ammonia, metals etc.

The optimum temperature range for salmonid culture is approximately 4°C to 16°C depending on the particular life stage.

Successful hatching will normally take place between 4°C and 8°C, and above this eggs will die and below it hatching success may be poor. First feeding of fry is best undertaken between 7°C and 10°C and ongrowing of older fish is optimal at 16°C (Laird and Needham 1988). At temperatures greater than this, fish are more likely to suffer from health problems e.g. Furunculosis or PKD, if the causative pathogens are present in the farm or water supply.

Finally, rapidly fluctuating temperatures are also stressful for salmonids and may lead to mortalities if the change exceeds more than two degrees over seven days. One hatchery manager in Ireland reported an 8% loss in his stock when temperatures rose from 15°C to 20°C in 5 days.

pH

The pH ($-\text{Log}_{10}[H^+]$)of a water supply is one of its most important waterquality characteristics not only because of its direct affect on fish but also because of its affect on the chemical activity and toxicity of many other substances in solution e.g. ammonia, nitrite, certain heavy metals etc.

EIFAC (1980) recommend that a suspended solids level of 15mg/l would be suitable for aquaculture.

Dissolved Oxygen

Dissolved oxygen is probably the single most important waterquality feature of salmonid waters and fish farms. Salmonids in general have a high requirement for dissolved oxygen and the success of a wild fishery or a fish farm will rest on the availability of an abundant supply of this gas most of the time and an assured minimum level at *all* times.

Oxygen requirement vary considerably and are dependent, among other things, on the ambient temperature, the size of the fish, as well as the activity level and feeding status of the fish.

As the ambient water temperature increases, two things happen with regard to dissolved oxygen. Firstly the amount of oxygen present in the water decreases and secondly the fishes requirements for oxygen increase due to a temperature related increase in metabolism. The extent to which the oxygen content of water varies with temperature is illustrated by the following figures which give the concentration of dissolved oxygen (mg/l, O_2) in fully saturated water at three different temperatures.

Temp °C	D. O. (mg/l)
5	12.77
10	11.28
20	9.08

As the water temperature on a fish farm goes from 6°C to 20°C, the respiratory oxygen requirements of rainbow trout increase three fold; salmon are likely to have similar requirements . This clearly shows that any farmer intending to hold a heavy stock of fish during the summer would need to plan carefully for the oxygen requirements of the stock. This is likely to be more critical for rainbow trout farmers than smolt producers as the former tend to hold heavier stocks during the warm months of the year.

Fish size is also an important factor affecting a fishes oxygen requirements , smaller individuals consuming more oxygen per unit body weight than larger ones e.g. at 12°C, a 100g rainbow trout consumes 250 mg O_2/kg/h whereas a 30g trout at the same temperature requires 300 mg O_2/kg/h.

As safe criteria for dissolved oxygen in salmonid waters, EIFAC recommend a median limit of 9 mg/l and a 95% limit of 5 mg/l . Based on the EIFAC studies, the EEC directive set even tighter standards stipulating a 95% minimum of 7 mg/l for designated salmonid waters. Indeed the latter figure is more appropriate for aquaculture because because even though salmonids may survive for extended periods at 5.0 mg/l and in some intensive systems these levels may occur, nevertheless, it has been shown that when fish are on full rations they require water with dissolved oxygen levels close to 100% saturation in order to fully utilise and convert their food.

Research has also shown that eggs have a high requirement for oxygen. Studies carried out on redds in the wild, suggest that no eggs can survive at oxygen levels below 4-5 mg/l and that for significant levels of survival, 8 mg/l should be ensured.

Ammonia

The bacterial decomposition of nitrogen containing organic matter e.g. protein gives rise to ammonia which is ultimately oxidised to nitrite and nitrate. Ammonia is also a major by-product of protein metabolism in fish and is excreted via the gills.

In freshwaters, ammonia is measured as total ammonia which exists as an equilibrium between a non-toxic ionised species (NH_4^+) and an unionised species (NH_3) which is toxic to salmonids in very low concentrations.

The relative proportions of ionised and unionised forms present in solution will depend on the pervailing temperature and pH, especially the latter. As temperature and pH rise so also does the unionised form (NH_3) .

The EEC directive sets a mandatory waterquality limit maximum of 0.025 mg/l (NH_3) and a guideline limit of 0.005mg/l. Despite the fact that these levels seem very low, the amount of total ammonia required to give these levels in solution are quite significant. For example, the total ammonia concentration required to to produce the EEC mandatory limit of unionised ammonia in solution (0.025 mg/l) at 15°C and pH 6.5, pH 7.5 and pH 8.0 are 23 mg/l, 2.3 mg/l and 0.75 mg/l respectively. The first two of these concentrations are very unlikely to be reached in flow through farms, however, the lowest concentration could conceively be attained in intensive rainbow farms. Surface waters and ground waters contaminated with organic waste, particularly from agricultural sources, are more likely to be the route by which ammonia could cause waterquality problems on flow through fish farms.

Metals

A variety of metals occur naturally in surface and ground water sources, or as contaminants from mining and industry in particular. They can also be derived from metal components used in the plumbing system or tanks in fish farms, though this is probably a very rare occurrence nowadays. In recent years, certain metals, particularly aluminium, have become more important since research has shown them to be implicated in the widespread decline of salmonid fisheries in countries affected by acid rain.

Metals occur in natural waters in a variety of forms, each of which may have very different toxicities. Metals may be present in solution or bound to organic compounds e.g. humic acids. In practice, however, it is very difficult to distinguish between these by analysis and therefore, metals are normally determined as dissolved or total metal.

The toxicity of metals may be influenced by a variety of other waterquality variables e.g. hardness, pH etc. As a general rule, the harder the water or the more organic matter present, the lower the toxicity of a given metal. To illustrate these trends, a number of the more important metals are reviewed in brief below.

Copper

The toxicity of copper is strongly related to the amount of the cupric ion (Cu^{++}) in solution. However, this species readily reacts with carbonates, hydroxides and organics e.g humic acid thereby reducing its toxicity significantly. The toxicity of copper is also affected by temperature, dissolved oxygen, total hardness and pH, particularly the latter two. Increasing pH and more especially hardness, significantly reduce its toxicity.

In soft waters copper can be toxic even in very low concentrations, e.g. the 96 hour LC50 of adult rainbow trout (i.e the concentration at which 50% of a test batch of fish died over 96 hours) in water of 14 - 45 mg/l as Ca CO_3 hardness was 0.02 -0.10 mg/l Cu. Concentrations at the lower end of this scale can reduce the hatch of Atlantic salmon eggs in very soft water (14 mg/l as Ca CO_3)

It has also been noted in relation to copper that the younger stages appear to be most vunerable.

The tentative waterquality standards for copper given by the EEC directive (based on EIFAC reviews) are as follows:

Water Hardness (mg/l,as $CaCO_3$)	Dissolved Copper (mg/l, Cu)
10	0.005
50	0.002
100	0.040
300	0.112

Zinc

The toxicity of zinc to fish has been well documented and like copper its toxicity decreases significantly with increasing water hardness, though overall it is less toxic than copper. Also, increased levels of suspended solids and increasing salinity, especially the latter, are known to reduce the toxicity of zinc, whereas, a sudden drop in dissolved oxygen increases it.

Experiments with a range of salmonid species have shown that the earlier free living stages are more vunerable than older fish. However, rainbow trout eggs were shown to be four times more tolerant than adults. At the same time, Atlantic salmon eggs are known to be very sensitive to zinc in soft waters. Finally, it is noteworthy that salmon become significantly more sensitive to zinc during smoltification. Tentative maximum 95 percentile limits for zinc given by EIFAC are as follows :

Water Hardness (mg/las Ca CO_3)	*Soluble Zinc (mg/l, Zn)
10	0.03
50	0.20

100	0.30
500	0.50

* The EEC directive specifies *total* zinc for the same figures.

Iron

Iron is one of the most abundant metals in surface and ground waters in Ireland, however, its impact on fisheries has not been studied in as much depth as other more toxic metals e.g. copper or cadmium.

One researcher found that ferric hydroxide at a concentration of 3 mg/l, Fe was lethal to trout when it percipitated on the gills having come out of acid solution at pH 5.5. In the past two years, iron in borehole supplies was strongly implicaed in serious mortalities of eggs and fry in two hatcheries in Ireland. As yet , EIFAC has not set waterquality criteria for this metal.

Aluminium

The toxicity of aluminium is strongly influenced by pH being significantly higher at pH values less than 6.0. Calcium at or above 2 mg/l has been shown to ameliorate the impact of aluminium in soft water, at sites where it is a problem. As yet no "official " waterquality criteria have been agreed for this metal, however, Watson (1988) suggests that farms or hatcheries should not be established on waters where the pH is less than 5.6 and the aluminium concentration greater than 0.025 to 0.030 mg/l,Al.

Conclusions

The foregoing account gives some indication of the complexity of the interaction between salmonids and their watery environment and how this can vary with such factors as age, size and smoltification status. It is also evident that the toxicity of any given waterquality variable may be strongly influenced by other features of the water chemistry of a water source. For this reason therefore, if an accurate assessment of the suitability a water source for salmonid farming is to be made, then as broad as possible a selection of key constituents need to be analyesd

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A Discussion

of

Groundwater Sources

For

Fish Farming

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GROUNDWATER SOURCES FOR FISH FARMING

INTRODUCTION

Groundwater is used throughout the world as a major source of fresh water and in the coming years this situation will be repeated in Ireland.

Many industrialised countries rely on groundwater for more than 50% of their total public water supply requirements with some large water consuming or "wet" industries relying totally on groundwater abstractions for their process waters. The use of groundwater over much of Europe has reached a point where both domestic and industrial wells are licensed by Government with a view to controlling the abstraction from particular aquifers and to prevent over pumping.

Groundwater has, to date, not played a major role in the supply of potable water in Ireland as a whole because of the abundance of surface water sources and low population. However, some counties rely 90% - 100% on groundwater for potable water but this picture is not reflected in the national figures due to the swamping effect of Dublin's and Belfast's supplies. This picture is slowly changing nationwide as the potential for groundwater development becomes better documented and more large groundwater based water schemes come on stream.

While the larger regional water supply schemes have historically been based on surface water sources this has not been the case for the many hundreds of group schemes throughout rural Ireland and more importantly for the relatively high water consuming industries located away from the regional schemes such as creameries, breweries and meat factories. It was these randomly located groundwater developments that provided the first indications that many parts of the island were underlain by important aquifers. This information, together with numerous documented well drilling programmes carried out in the last 15 years has provided a basis on which to plan future groundwater abstractions anywhere in Ireland. In addition, it is now possible to direct industries such as fish farm developments to areas with large groundwater potential.

GROUNDWATER

What Is It ?

Groundwater is the hidden part of the hydrogeological cycle; i.e. it is the component of rainfall that moves unseen below ground surface to discharge into the rivers and streams or to the sea along the coast. The quantities of groundwater feeding the main rivers become visable during the summer months when the rivers keep flowing after months of low to nil rainfall. It is a renewable resource in that the winter rains replace the volumes of groundwater discharged during the drier summer months. Ireland's surplus of rainfall over evaporation always insures that groundwater aquifers are nearly always fully recharged on an annual basis. In fact, most aquifers reject potential recharge.

Where Does It Occur ?

Groundwater is found everywhere in Ireland, or nearby everywhere to be correct. It occurs below the water table infilling the pores and fissures in the overburden and the bedrock. The potential for any geological unit to provide large volumes of groundwater depends on the permeability of the strata, the greater the permeability the large the individual well yield. The storage within the geological units will determine the ability of the strata to provide groundwater during dry or drought conditions.

Geological units which provide useable supplies of groundwater are called aquifers, ranging from minor aquifers supplying domestic demands to major aquifers which are capable of very large supplies of groundwater.

Where To Look For Large Supplies Of Groundwater

The answer to this question must be everywhere in Ireland because of

1. the geological history and structure of this island and

2. the lack of detailed hydrogeological information.

Obviously, it is impossible to develop large supplies of groundwater everywhere on the island, if it was there would be no need for consulting hydrogeologists. In reality large tracts of land are underlain by impermeable strata but the extent of these areas is difficult to define. Furthermore, even in areas underlain by impermeable strata it is possible to locate locally important groundwater supplies which would suffice for these stages of fish farming which require relatively low volumes of good quality fresh water.

The potential to develop large volumes of groundwater in a particular area depends upon the;

(i) underlying geology

(ii) volumes of groundwater required

(iii) amount of land available for well drilling

(iv) water quality requirements.

GEOLOGY

The geology of a particular area governs its potential as a major source of groundwater. If the area is underlain by a major aquifer then the potential is good, if not, a lot of money can be spent trying to achieve the impossible i.e. to get water out of a stone! Unfortunately, while very broad statements can be made about the regional potential of various rock and sediment types, Irish geology X is too complex to provide site related predictions without trial well drilling programmes. So a statement that Irish limestones constitute major aquifers is misleading in that many limestones are impermeable and constitute very minor aquifers indeed. Similarly, the same can be said of the volcanics, sandstones and glacial deposits which occur all over the island.

VOLUMES OF GROUNDWATER REQUIRED

As already stated groundwater is available nearly everywhere with the permeability of the underlying strata controlling the amount that can be abstracted at any particular site. Experience has shown that most parts of the country, regardless of underlying geology, can supply individual well yields of 1 litre/sec or greater. So, allowing for four wells positioned at the corners of a small plot of land most sites should be capable of developing a supply of 4-5 litres/sec. The more productive aquifers provide individual well yields in the range of 13-26 litre/sec with some wells being capable of 50/litre/sec. Therefore, where small sites are underlain by a major aquifer 2-8 wells would be required to supply a demand of 100 litre/sec.

LAND AVAILABLE FOR WELL DRILLING

The permeability, thickness and storage of an aquifer control individual well yields. Therefore, while a particular aquifer may be capable of supplying 100 litre/sec it may be necessary to locate a number of wells 50-100 m. apart to abstract the 100 litre/sec. In the case of the very important aquifers it may be possible to use 1 or 2 wells but normally 4 - 8 wells would be required. In the latter case access to lands larger than the usual fish farm would be required as it is important that such high yielding wells be located sufficiently far apart to limit their interference.

WATER QUALITY REQUIREMENTS

Of equal importance to the volumes of groundwater available is its quality. This is controlled by the host rock or sediment and mans' activities in the recharge zones. Groundwater quality varies tremendously from aquifer to aquifer and it is wrong to make any definite quality predictions at a particular site in advance of drilling and test pumping.

SPRING DEVELOPMENT

Instead of a diffuse discharge into rivers, lakes or the sea groundwater is often seen to discharge at a single point in a spring. Where these discharges are large and predictable they offer the best option in groundwater use as the need for pumping is reduced and in some cases fully eliminated.

Spring investigation and development are similar to that carried out at surface water abstractions where the summer low flows and quality variations are important. In this respect it is important to understand the geology of the aquifer and the farming activities in the recharge zone.

RECOMMENDATIONS

Experience of groundwater development in Ireland would suggest the following;

(i) It is always worth investigating any site with a trial well regardless of regional drilling results.

(ii) In searching for a green-field site try to locate the proposed development as close as possible to existing successful groundwater abstractions.

(iii) Never drill a production well without having tested the quality and quantity available at each site with a trial well.

(iv) Always have an option to purchase a green-field site in advance of trial well drilling programmes.

(v) Get professional hydrogeological advice.

FISH FARMING IN IRELAND - AN OVERVIEW

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1.0 Introduction

My brief, in preparing this paper, was to present an overview of fish farming in Ireland. However, because of the overall theme of this Conference and the dramatic growth of salmon farming in recent years, the paper will place emphasis on salmon smolt production and on the advantages and disadvantages of using ground-water.

2.0 Freshwater Fish-Farming in Ireland

The trend in farmed fish production has changed dramatically in Ireland since the early eighties. Prior to this date, pen-rearing of salmon in the sea did not exist in Ireland and salmon hatcheries were used for the restocking of rivers in which populations had been depleted due to river drainage or to hydro-electric developments. The main salmon hatcheries were operated by the Electricity Supply Board, the Salmon Research Trust or by Fishery Boards. The rearing of brown trout for stocking purposes is still carried out by the Central Fisheries Board.

Rainbow trout have been farmed in Ireland since the sixties, but this operation did not show the dramatic increase which was experienced in some other European countries. However, in recent years, some sea-sites have commenced on-growing rainbow trout in sea cages and this has increased the demand for the fresh-water production of this species.

The dramatic revolution in salmon smolt production commenced in Ireland in the early eighties, with the introduction of the cage-rearing technology as developed in Norway and Scotland. Table 1 shows the increase in smolt production from an estimated 200,000 in 1981 to 7.5 million in 1989. During this period also, Ireland's production of farmed salmon increased from 35 tonnes in 1981 to 7,200 tonnes in 1989.

They are then introduced to the processed food. The feeding rate and consequently growth rates of the fish is greatly influenced by water temperature and $6^{O}C$ is taken as the critical level, below which little feeding takes place.

The fish must reach a critical size by the following Spring to allow them to become smolts. This size is approximately 30gms, but varies with fish strain. Smolts are fish that undergo physiological changes which allow them to survive in marine waters. The salmon that achieve this in one year are called S1 smolts and are transferred to sea cages, normally in March/April.

Salmon parr which do not achieve this critical size will not become smolts for a further twelve months and are then classified as S2 smolts. With modern salmon farming practice, it is generally uneconomical to retain S2 smolts in a tank farm for the additional twelve months. They are normally either transferred to cages in lakes, if planning permission exists or are sacrificed.

TABLE 2

LIFE CYCLE OF FARMED SALMON

Ova	Nov/Dec 1988
Eyed Ova	Dec/Jan
Hatching	February 1989
First Feed Fry	April
Fingerling	June
Parr	August

Greater than approx. 30 gms → S1-smolts → To sea

less than approx 30 gms → Parr (March 1990) → S2-smolts (March 1991) → To sea

4.0 Setting Up a Smolt Unit - Planning and Licence Requirements

These requirements are outlined in Table 3.

Planning Permission must be sought for a proposed hatchery under Section 26 of the Local Government (Planning & Development) Act 1963. It is not unusual for Local Authorities to request professional advice from relevant Government Departments such as the Marine, in relation to such applications.

Prior to development, a Fish-culture Licence is also required from the Department of the Marine. This department seeks the local advice and opinion of the relevant Regional Fisheries Board.

Should both of these be granted, the potential fish-farmer requires a licence, under the 1977 Water Pollution Act, to discharge effluent. The licence, if granted, will include limits on the effluent components and by controlling the volume of effluent being discharged, also obviously limits the volume of water being abstracted from the source.

To operate, two further licences may be required from the Department of the Marine. If the developer wishes to import eggs, they must have an Ova-import Licence. Finally before fish can be transferred from the farm to a sea site or to another freshwater farm, a Live-fish Transfer Licence must be obtained from the Department of the Marine.

TABLE 3

Salmon Smolt Production

Planning and Licence Requirements

Planning Permission	Local Authority
Licence to discharge Effluent	Local Authority
Fish-culture Licence	Dept. of Marine (Regional Fisheries Board)
Ova-import Licence	Dept. of Marine
Live-fish Transfer Licence	Dept. of Marine

5.0 Fresh-water Salmon Production Units

There are approximately 30 sites producing salmon parr or smolts in Ireland at present. They range in size from units producing 50,000 smolts to 1.5 million smolts per annum. Most operations are land based, using tanks. Less than 10 are lake based - that is units which on-grow salmon parr in cages held in freshwater lakes. However, some of these latter have very large production units with a capacity in the reigon of half a million smolts.

Of the land based units, less than five are dependent on groundwater.

5.1 Land-based Production Unit: A general outline design for a land-based smolt unit is presented in Fig. 1. The eggs are allowed to hatch in troughs in the hatchery, and in many cases first feeding also takes place there. When feeding is established the fry are transferred to the 2 meter and 4 meter tanks where feeding continues. As the fish grow they require more space and are normally transferred to 7 meter tanks in mid-Summer and remain here until smolt development takes place. The waste from the hatchery and the tank-farm is normally collected in a single channel and goes to the receiving water. For hygiene purposes, the area containing the 7 meter tanks is often seperated from the hatchery and smaller tank area.

The water requirement for a smolt unit is obviously dependent on the quality of the water and the size of the fish. Table 4 gives typical water requirements for a 250,000 smolt unit. It will be noted that the requirement ranges from 40L/Sec^{-1} in May/June to a maximum of 250L/Sec^{-1} in January/April, when the smolts are achieving maximum size.

For reasons described in Section 6.0, the units utilizing ground-water do not produce smolts but utilize the advantage of higher water temperatures early in the year, by producing early developing fry. These units are disadvantaged during the period when ambient temperatures are higher than those of groundwater. In addition, because of the very large number of fry which can be produced relative to smolt numbers for a limited groundwater volume, it is economically more attractive for these units to produce only fry.

TABLE 4

Typical Water Requirement for 250,000 Smolt Unit

January - April	0.25 m^3sec^{-1}
May - June	0.04 m^3sec^{-1}
July - August	0.06 m^3sec^{-1}
Sept - Oct	0.10 m^3sec^{-1}
Nov - Dec	0.15 $m3sec^{-1}$

5.2 Lake-based Units: Lake-based units take fry when they are approximately 5gms weight and on-rear them in cages in clean lakes. Capital costs are obviously lower, although growth rates may not be as good as in a tank farm. In Ireland, lake based units operate with fry supplied from both groundwater and surface water tank-farms.

Some-lake based units also rear S2 smolts, but the latter are more succeptible to disease.

6.0 Advantages and Disadvantages of Using Groundwater

6.1 Water Supply: When identifying a suitable development site, the fish farmer normally looks for a gravity feed from the water supply to the production unit. Groundwater, on the other hand, would generally require pumping, which is not only an additional 'running-cost' factor, but also requires additional capital outlay for diesel operated pumps for emergency use during electricity power failures.

From the water requirements presented in Table 4, it is clear that most groundwater sources are better suited to fry production rather than to the smolts.

6.2 Water Temperature   Table 5 gives a summary of the advantages in growth-rates, gained by using groundwater in the early months of the year. On groundwater, fry can be on first feed in February, whereas fish on surfaces waters may not reach this stage until the middle of April or later, depending on ambient temperatures.

This temperature advantage continues, normally until May, when ambient temperatures are consistently higher than those of groundwater. The fry are generally transferred to surface waters at this stage. However, in Norway, many sites heat the groundwater using cheap hydro-electric power. Obviously in late Autumn, the temperature of groundwater would again gain advantage over that of surface water. If salmon were allowed to develop on groundwater alone, it is likely that the percentage smolt production would be significantly lower than that achieved with fish transferred to surface waters during the warmer period of the year.

TABLE 5

SURFACE VERSUS GROUND WATER IN PARR PRODUCTION

Temperature Advantages

	Surface Water (ambient)	Ground Water (say 8ºC)
Ova Production	Late Nov. (say)	Late Nov (say)
Hatching	Late February	Mid January
First Feed	Mid April	Late February

From May to September, surface waters are likely to have a temperature advantage over ground waters.

6.3 Gases. This is a case of "swings and roundabouts", when comparing ground and surface waters. The concentration of gases in groundwater must be equilibrated with air to ensure that the dissolved oxygen is increased to saturation and, if necessary, that levels of carbon dioxide and nitrogen are reduced to acceptable concentrations.

Dissolved oxygen concentrations in surface water may however also vary, not only with pollution incidents but diurnally due to photosynthesis.

6.4 Suspended Solids: Suspended matter in water is a real problem in many hatcheries, particularly with young fry and during spates. Groundwater has a distinct advantage here, particularly around the period of first feed.

6.5 Colour: The natural colour in some surface waters, due to humates, does not harm fish and indeed may assist their development by increasing light absorption during very bright sunshine.

6.6 Organic Matter: The low concentration of organic matter is a very distinct advantage in relation to groundwater. There is less oxygen demand on the system and degredation products such as ammonia are also likely to be low.

6.7 Nutrients: In Ireland, nutrient concentrations in groundwater are generally lower than surface waters which may be subject particularly to surface run-off of artifical fertilizers and slurry.

6.8 Alkalinity/Hardness/pH: These factors are obviously influenced by the geology of the water source, whether surface or ground water. Perhaps the most significant aspect of alkalinity in fish farming is the provision of a buffering capacity to pH change and in its consequent influence on the solubility of heavy metals. In this respect, the presence of moderate alkalinity in water is a distinct advantage over soft waters.

6.9 Metals: In my own experience, metal concentrations of ground water often exceed those of surface water in the same region. Iron is perhaps the most common problem, although I have also encountered suspect concentration of copper and manganese in groundwaters.

6.10 Microbial Pathogens: Farmed salmon, because of the intensive production, are particularly sensitive to outbreaks of disease. Because of this, many developers seek river systems which do not have an indigenous population of wild salmon upstream of the farm-site. Wild salmon stocks are considered by many to be a possible source of both microbial pathogens and parasites. This is one of the very distinct advantages that groundwater has over most surface waters.

6.11 Receiving Water for Effluents: It is obviously critical, particularly in this time of hightened environmental awareness, that outfalls from fish farms does not cause a significant deterioration in receiving water. Most production units utilizing surface waters are located, because of their nature, beside a river or estuary. Farms utilizing groundwater must have a receiving water with sufficient flow to dilute the effluent, treated or otherwise, to acceptable concentrations. The availability of this receiving water may be a real limiting factor in the suitability of many groundwate sources.

7.0 Effluent Quality

Salmon farming is a very sensitive environmental issue at present and future development proposals are likely to undergo extremely close scrutiny from Local Authorities, Department of the Marine, environmental organizations such as An Taisce and the public. Because of the use of certain chemicals and antibiotics in smolt production, many Local Authorities have stated that they will refuse Planning Permission to proposed developments where the receiving water, regardless of the distance downstream, is utilized as a source of potable water. I believe a similar approach will be taken where the possibility of infiltration of effluent into groundwater exists. In addition, it is highly unlikely that there will be any further expansion of the number of cages in freshwater lakes and indeed there is great pressure from the public and fishery interests, to remove existing cages.

The results of a survey of effluent quality from fish farms in the U.K. is presented in Table 6. Perhaps the most significant aspect of this, is the high concentration of suspended solids in the outfall. A fish farm, in producing a tonne of fish per annum, also produces 1.35 tonnes of suspended solids in its outfall over the same priod. In the case of very large farms, the potential for producing eutrophication in down-stream lakes is very real.

Planning Permission granted in recent years to large land-based units, normally have a waste-treatment facility incorporated in the design. This treatment is most frequently utilized to deal with the suspended solids and may have little effect on the nutrient concentrations.

TABLE 6

Effluent Quality from Fish Farms*

Parameter	Mean (mgL^{-1})	Range (mgL^{-1})
BOD	5.43	2.11 - 14.0
Suspended Solids	20.6	8.18 - 51.8
Ammonia	0.41	0.09 - 1.97
Nitrate	1.98	0.52 - 7.58
Phosphorus	0.106	0.04 - 0.27

Rate of production of pollutants per annual production of fish*

Parameter	Net output/tonne of fish produced/year. (kg)
BOD	285
Suspended Solids	1,350
NH_3-N	55.5
NO_3-N	10.2
P	15.7

(*E.I.F.A.C. 1982 - survey of fish-farms in U.K.)

8.0 Conclusions

The use of groundwater in salmon production in this country has not been fully exploited. Its greatest advantages are in providing higher temperatures for the early development of egg and fry, the absence of suspended solids and its sterile status in relation to fish parasites and microbial pathogens.

Groundwater can be used to the best advantage in the industry by producing well developed salmon fry for transfer to surface waters, when ambient water temperature exceeds that of ground water. With temperature enhancement, it is possible that some groundwater sources might produce two separate batches of fry each year. It is unlikely that the production of smolts, reared solely on groundwater, will be an economic proposition.

THE BUSINESS OF AQUACULTURE

1. Aquaculture is the cultivation of aquatic organisms under controlled conditions. It has three major product sectors, three broad technologies and three scales of intensity.

Products	Intensity	Technology
Finfish	Intensive	Marine
Shellfish	Extensive	Freshwater
Seaweed	Capture	Recirculation

For the purpose of this paper, I am only concerned with that aspect of aquaculture which cultivates aquatic organisms for human consumption in intensive conditions.

The business of aquaculture can be looked at from many perspectives just like any industrial sector. My purpose is to provide you with an insight into some of the demands that make aquaculture a source of wealth creation because this is at the core of most proposals for investment and development in our society.

2. Global Perspective

The production of fish for human consumption has been based on the hunting of wild stocks rather than the cultivation of domesticated wild stocks for time immemorial - compare with beef, pigs, chickens, etc. The techniques of animal husbandry have been practised in fish production for thousands of years - Chinese carp have been reared in paddy fields for at least 2,000 years.

World production of all fish is about 80 million tonnes/year - about 16 kgs per person. Aquaculture in all its forms contributes 10 million tonnes or 2kg/person.

To put this into perspective, compare world fish production with world production of other familiar foodstuffs.

Fig. 1 World Food Production 1985

	Million MT	%	Kg/p/yr.
Cereals/Root Crops, etc	2,472	60	494
Vegetables, Fruit & Nuts, etc	729	17	146
Meat	148	4	30
Milk and Eggs	538	13	108
Oil and Sugar, etc	162	4	32
Fish	80	2	16
TOTAL	4,129	100	826

Source: FAO per capita data based on 5,000 million population.

Any person who has travelled abroad or watches TV will be aware of regional and national variations in diet. The Japanese are famous for fish consumption. Central states in the US are famous for beef while Boston is famous for fish ...... etc, etc. At a continental level, the fish data looks like this:-

Fig. 2 Output of Aquaculture 1975 to 1985 and Projections to 2000

	Million MT	1975	1980	1985	2000
Region	Africa	N/A	N/A	-	0.1
	Asia & Pacific			9.0	18.3
	Europe & Near East			1.5	2.7
	Americas			0.7	1.2
Species	Fin Fish	4.0	3.5	4.4	9.7
	Molluscs	1.0	3.4	3.2	7.1
	Crustaceans	0.1	0.1	0.1	0.3
	Seaweeds	1.0	2.4	2.4	5.2
	TOTAL	6.1	9.4	10.2	22.2

Note the concentration of fish produced in Asia and the relatively limited production in Africa. The North American and European figures are important because they are the key markets for Ireland.

Projections for future production in these key markets are critical to the future of intensive aquaculture.

Fig. 3 World Fish Demand 1985 and 2000

Year	1985	2000 (Estimated)
(a)		
Population (Million)	5,300	6,000
Per Capita Fish Consumption	15kg	17kg
Implied Demand (Million MT)	80	102
Shortfall (Million MT)	-	12
(b)		
Aquaculture (Million MT)	10	22
Wild Fishery (Million MT)	70	80
	80	102

Due to restrictions on the capture fisheries, the scope for growth in output of fish is very limited, especially in Europe. This, combined with rising demand for fish in this market, is creating an unprecedented demand for aquaculture products.

Fig. 4 European Aquaculture Output 1984 (000s MT)

Countries	USSR	300
	Spain	168
	Netherlands	122
	Italy	108
	France	110
	Others	413
Species	Fin Fish	726
	Molluscs	495
	Crustaceans	-
	Seaweeds	-
	Totals	1,221

At a recent conference in Scotland, it was estimated that:

(a) Consumption of fish in Europe will increase from c.14kg/cap to c.20kg/cap by 2000 (extra 1.6 million tonnes p.a).

(b) Half of this growth will have to be met by aquaculture - (0.8 million tonnes p.a).

This is the driving force behind the expansion of aquaculture in Europe.

3. The Irish Perspective

The production of aquaculture in Ireland is summarised as follows from BIM data:-

Aquaculture Output - 1987

Species	Tonnes	Value (IR£)
Salmon	2,232	10,122,120
Sea Trout	320	691,000
Trout (Freshwater)	600	1,150,000
Rope Cultured Mussels	1,500	675,000
Bottom Cultured Mussels	13,393	1,187,892
Intensive Native Oysters	160	562,500
Extensive Native Oysters	317	864,339
Instensive Pacific Oysters	104	123,250
TOTAL FARMED FISH	**18,626**	**15,276,358**

BIM 1987

Aquaculture produces less than 10% of the product but accounts for over 30% of the value. In 1990, the split will be closer to 50/50 and this will be due entirely to the expansion of salmon farming which has grown from less than 100kg in 1980 to 10,000 tonnes in 1990.

The attached maps give an indication of the distribution of A. finfish and B. shellfish production in the country. There are over 70 salmon and trout farming sites in operation and these will increase dramatically over the next 3 to 5 years if the pattern in other countries is to be followed. The following figures for salmon farming in Scotland suggest the scale.

	1988 No. Sites	1988 Output		1990 Output
Marine	197	18,000t		30,000
Freshwater - cages	72	12.2m		
- tanks	104	11.0m	Smolts	30M

Freshwater Sites

Rainbow trout, salmon smolts and brown trout for restocking are the main species produced in freshwater in Ireland. Salmon smolts are the major pressure points at this time so my comments will focus on these.

To achieve 30,000 tonnes of farmed Atlantic salmon in 1995, the Irish salmon farming industry will have to transfer at least 15 million smolts to sea in spring 1993. To do this, at least 30 million ova have to be laid down in commercial hatcheries in January/March 1992.

Model Production Cycles

1990	1991	1992 Jan	1993 Jan	1994 Jan	1995
	Smolts 10m	Harvest Salmon 15,000t			
Ova 24m	Smolts 12m		Harvest Salmon 20,000t		
	Ova 28m	Smolts 14m		Harvest Salmon 25,000t	
		Ova 30m	Smolts 15m		Harvest Salmon 30,000t

meet the expected demand for additional smolts in 1993 at least 50% increase in capacity is required to be in place by mid-1992.

The water demand of a smolt unit can be met by either piping through a tank farm - gravity feed is the only economic approach or by rearing the smolts inc ages anchored in a suitable lake - over 50% of Scottish smolts are produced in this way and over 30% of Irish output similarly.

Electricity costs make pumping of large volumes of water in Ireland uneconomic. At peak load, just before transfer of smolts, a unit needs c.1 litre of water per second for each 1,000 smolts (50g) on site, ie a 500,000 smolt unit needs 500 litres/second in February-May each year. 20% of this flow will suffice for most of the rest of the cycle.

4. Economics

Taking a 250,000 smolt unit as an example, the following model is indicative of the costs involved.

(a) Facilities

Hatchery	
Tank Farm	Very Site Dependent
Site and Buildings	
Miscellaneous Equipment	
	£400,000

(b) Operations

Ova	350,000 @ 5p	17,500
Feed	250,000 x 50g x FCR2 x £800/t	40,000
Labour	10 x £10k/yr	100,000
Transport	2p/fish	5,000
Insurance	4% of sales	10,000
Vet/Water		10,000
Overheads		60,000
Depreciation (10 years)		40,000
Bank Interest (15% on £100k)		15,000
		£297,500

To break even, this unit needs an income of almost £300,000 p.a or £1.20 per smolts. It will need capital resources of at least £500,000 and a positive bank manager.

To generate say 25% return on equity of say £200,000 requires profits of £50,000. The income, therefore, needs to be as follows:-

Income:	250,000 @ £1.50	£375,000
Expenditure		£297,000
Surplus		£ 78,000
Tax 10%		£ 8,000
Net Surplus		£ 70,000
Dividend		£ 50,000
Retained/Reserve		£ 20,000

This is a risky business. The species is only 6 or 7 generations from the wild and is extremely sensitive to changes in water quality and general environment. Salmon are susceptible to diseases which are not damaging in the wild but can be fatal under conditions of intensive cultivation.

There are considerable benefits to Ireland.

A. Regional Development.

B. Value Added in Ireland.

C. Exports

D. Employment.

E. R & D.

5. Conclusions

1. Commercial aquaculture has truly arrived in Ireland in the past 5 years with the development of Atlantic salmon farming.

2. This is a result of market opportunities and technical developments in animal husbandry.

3. Existing pressures and competition for water resources will increase in the next 5 years.

4. The major hydrogeological pressure will be in freshwater for smolt production - springs, rivers and lakes. Significant developments will also arise in sheltered marine sites.

5. There are significant benefits to Ireland in this new wave of natural resource based high value added enterprise.

6. Development will need to be orderly, sympathetic and rational - requiring inputs from regulatory agencies:

-	Department of the Marine	-	aquaculture licence
		-	live fish transfer licences
-	County Councils	-	planning permissions
		-	effluent discharge licence
-	BIM/Udaras	-	State aids/EC grants
-	IDA/Udaras/SFADCo	-	Fish processing
-	Department of the Environment	-	Drinking Water Quality Standards

We strongly advise and recommend that public servants involved in these areas familiarise themselves with the industry by visiting existing farms and establishing files on critical aspects. Please try to keep fact and fiction apart and don't miss out on an excellent opportunity to develop new enterprises in your area.

Liam Keilthy

20 March 1989