NRA NORTH WEST 69

NRA

National Rivers Authority
North West Region

GUARDIANS OF THE WATER ENVIRONMENT

REVIEW OF WATER RESOURCES IN THE FYLDE AQUIFER AND WYRE CATCHMENT

MAY 1994

SUMMARY

In the development of the National Water Resources Strategy, redeployment of Vyrnwy water is one of the options examined. A desk study for North West Water Ltd. into feasible resources to replace this water suggested that about 80 Ml/d would be available by removing physical constraints on the operation of the Lancashire Conjunctive Use Scheme (LCUS) sources and realizing the total licensed quantities.

This report considers the LCUS and its relation with the River Wyre catchment, where operational experience of the various abstractions, both surface and ground water, in the catchment have given numerous low flow problems.

The catchment is under considerable stress in dry, summer periods, from the current abstraction regime. Any further groundwater use is likely to increase the dry/low flow periods, with possible associated environmental damage. Because of the need to protect current abstractors and the environment, the Region has an embargo on any further development, even by small individual abstractors, pending a detailed review of available resources.

The report recommends an in-depth study of the LCUS groundwater resource and its relation with the surface water aspects in order to develop future management policies.

REVIEW OF WATER RESOURCES
IN THE FYLDE AQUIFER AND WYRE CATCHMENT

Appendices

NATIONAL RIVERS AUTHORITY - NORTH WEST

May 1994

1. INTRODUCTION

One of the initial suggestions from the national Water Resources Strategy to increase the water supplies to the South and East of the country, is to redeploy water from the Vyrnwy system in N. Wales. Currently this is a major source for NWW Ltd. in the NW region, and consultants carried out a desk study into feasible sources to act as replacement. It was noted that the LCUS abstractions (NWW Ltd.) were restricted by distribution constraints to 180 Ml/d rather than the quoted licenced yield of 260 Ml/d. This seemed an obvious source of an additional 80 Ml/d.

A recent paper (Appendix A) addresses the economic evaluation of Lake Vyrnwy as a component of NWW water supply system, and includes some background to the national Strategy studies.

Operational experience has shown a number of low flow problems over the years, some having been exacerbated by borehole pumping. Abstractions have taken place entirely within the legal entitlement, but when the original abstraction conditions were set, the needs of the environment were not as well understood or had as high a priority as today.

Unease at the possible second order effects on the LCUS of including Vyrnwy in the National Strategy, with the distinct likelihood of enhanced abstractions causing further environmental problems, has prompted this study.

The low flow problems have been identified at National level and their alleviation is a North West Region Corporate Plan objective.

2. NEED FOR REVIEW

Although NWW Ltd. are the major groundwater abstractors from the Fylde aquifer, ICI Ltd. have a group of licensed sources in the north of the area, and BNFL and Whitbreads have sources to the south near Preston. (figs. 1 & 2)

Abstraction by NWW tends to be concentrated on those groundwater sources with relatively low pumping costs, ie those which are in hydraulic continuity with and so derive their recharge from the watercourses. If the low flow problems are to be addressed whilst maintaining the NWW groundwater abstraction at its current level to meet existing demands, less efficient and 'poorer' quality licensed groundwater sources may have to be utilised. This has obvious operational and financial implications.

Recently there has been increasing interest shown in smaller scale groundwater abstractions across the aquifer, principally for industrial and commercial purposes in the Preston area and for agricultural/horticultural use in the rural areas to the north. Any determination of such applications has, of course, paid due regard to protecting existing users interests, and ensuring they were not derogated.

The region has imposed an embargo on authorising any additional abstraction from the Fylde aquifer, pending the findings of a detailed re-appraisal of the available groundwater resources and their interaction with surface water.

There is thus an urgent need to develop a consistent policy for future management and licensing of the groundwater resources of the Fylde. This has been identified as a Regional Corporate Plan Objective.

3. OPERATIONAL EXPERIENCE

3.1 - NWW Ltd. has been operating its Fylde groundwater sources since the 1960's and using them conjunctively with surface water since 1979. During this period comprehensive groundwater level monitoring has been carried out in both the abstraction boreholes and numerous observation boreholes sunk as part of the earlier Fylde investigation. (fig.2). Appendix B summarises the physical details of the catchment and reviews the development of surface and ground water for supplies.

After the major pumping tests in 1972-74, the terms and conditions of the licences for the LCUS were confirmed, and essentially written to help to achieve a balanced use of the aquifer from north to south.
The history of modelling and simulation of water resources in this area and the development of conditions on the LCUS licences are summarised in Appendix C.

Because the boreholes are operated in groups, subject to 3 year as well as annual licence limits, and the actual abstraction pattern and duration varies from year to year according to demand, operational and licence constraints, it is difficult to carry out a simple analysis of the effects of such abstraction.

Furthermore , NWW's operating strategy of preferential use of their more efficient and high quality boreholes has altered the distribution of abstraction across the aquifer. This is illustrated by the hydrographs for the last 20 years of key abstraction sites (figs.3A-E). For example sites P,Q and R have been used only since 1984 (fig.3D). It is also evident that the boreholes have been used more intensively during dry years (84, 89, 90, and 91).

3.2 In addition to the river augmentation requirements, the LCUS licence is subject to hands-off level conditions relating to two observation boreholes (shown on fig 2).
Fig.4 illustrates the groundwater level trends over the last 20 years. These conditions were incorporated following the modelling of the aquifer, and were intended to protect the resources and groundwater users to the SE and SW of NWW's abstractions.

Levels have gradually declined in both holes, and levels in T74 (SD43/19) have dropped below the threshold but now show a little recovery. Levels in T68 (SD53/33) are below the control level.

The licence condition relating to borehole T68 has now been removed (because the main industrial user to the SE had ceased trading), but these two hydrographs indicate that resources are limited in the south. It is unlikely that significant increases in actual abstraction could be sustained without breaching the existing licence conditions. The environmental impact of further decline in levels has not been assessed.

3.3 The ICI boreholes, in the north of the aquifer, have shown evidence of saline intrusion in the past. In the early 1950's, daily abstraction was over 23 Ml/d, and this caused saline intrusion from the north. Abstraction was gradually reduced to about 9 Ml/d in 1960 which seemed to obviate the problem. The current licensed amounts are 5455 Ml/annum, with a maximum daily of 15 Ml/d.

Between 1973 and 1988 ICI only abstracted minimal quantities. However since then the company have increased actaul abstraction to 1200-1600 Ml/a, throughout the year. This has caused groundwater levels to decline, although they still remain above Ordnance Datum (fig.5). The widespread and persistent response of the aquifer to continuous (perennial) abstractions, and the need to maintain a balance is demonstrated by this response.

3.4 Before development of the aquifer there were several areas of groundwater discharge to the Wyre and Cocker catchments in the NW of the aquifer, where heads were at, or above ground level ie. artesian. These high heads have supported wetland areas and spring discharges (the latter mainly used for agricultural purposes). This is also reflected in reference to the 'Running Pump' Inn at Catforth.

As abstraction increased, thus reducing the piezometric head, the springs ceased. The Fylde Water Board, recognising the effect of pumping, converted many of the spring-fed cattle troughs to mains. Lowering of the groundwater head has allowed the ground to dry out quicker allowing earlier access to fields. Beneficial as this may be to agriculture, there are consequences in the drying out of many conservation areas.

3.5 The pumping tests carried out in 1972-74 showed that the flows in certain water courses were reduced by abstraction from the aquifer. Experience gained during the operation of the LCUS has confirmed that the Fylde groundwater abstractions do have a significant impact on surface flows to the detriment of the river environment.

The surface water abstractions, from the upper reaches of the rivers, have a similar impact on certain stretches, rendering them sterile from a fishery point of view. Fig.6 shows the stretches of rivers which are known to either dry up or have reduced flows in summer periods.

4. CONSERVATION ISSUES

4.1 There are a number of areas of conservation interest within the aquifer area. These include designated sites of national importance, SSSI's, and regional sites, SBI's, where lowering of groundwater levels may have an adverse effect. These are Winmarleigh Moss (SSSI), Cockerham Marsh (SSSI), Lune Estuary (SSSI), Carr Green (SBI) and other SBI's. In addition there are many nature walks and trails, some of which are along rivers, eg River Brock, and 'non-designated' sites which are still areas of significant conservation interest within NRA's environmental purview. (fig.7)

Other areas of importance from a conservation viewpoint are ponds, spring lines, and wet boggy areas. Certain protected species, eg the Great Crested newt, require not just ponds to breed in but also associated damp grassland. (Two sites in the area).

Carr Green and Winmarleigh Moss are drying out, as are other non-designated sites. Many ponds and small watercourses do dry up in dry summer periods and the drying up of these wetland features is a major cause for concern in wetland conservation.

4.2 The Wyre catchment supports recreational fisheries for migratory salmonids, resident trout and coarse fish. A recent study was carried out (Walsingham, 1992) to assess the salmonid and coarse fish population of the Wyre catchment. This also looked at distribution of spawning and nursery areas and species distribution.

The survey indicated that natural recruitment is poor, ie limited numbers and distribution of juveniles, both for migratory salmonids and coarse fish. A number of factors contribute to this; availability of spawning/nursery grounds, amount of wet area, barriers to migration, acid stress. The area of water available (wet area) limits the concentration of fish. As this decreases with low flows so the number supported decreases.

In particular, low flows in the Calder and Grizedale Brook cause a loss of spawning and juvenile nursery habitat for migratory salmonids. The abstractions from these watercourses result in the drying up of reaches during low flows, with a complete loss of fish habitat.

5. CONCLUSION AND RECOMMENDATIONS

5.1 The current regime and rates of abstraction from both surface and ground water in the Wyre catchment and Fylde area are giving rise to low flow conditions and the drying up of areas of ecological interest, in dry weather periods.
There is concern that additional abstraction (to support transfer of water to other regions), even if authorised in licences, may cause irreversible effects and greater environmental damage.

5.2 There are a number of signs of the inability of the system to sustain abstraction without having an impact on surface water and conservation interests during dry periods, under the current abstraction regime. Any modification (increase) in abstraction to meet with National Water Resources Strategy will almost certainly be environmentally unacceptable, and in breach of the Authority's duties to protect and improve the water environment.

5.3 The original LCUS licence constraints (threshold levels, prescribed flows, augmentation and 3 year limit) have been proven to be essential, but inadequate to prevent the low flow problems. Annual abstraction totals (especially groundwater) give an unrealistic indication of sustainable yield.

5.4 The 3 year limit on total abstraction (equivalent to twice the annual limit) affects NWW's security of supply, even under the current operating regime.

ICI is a joint user of the aquifer (in the north) and overall licensed totals take this into account in the conjunctive use totals for the LCUS. Excessive groundwater use in the past has been shown to encourage saline intrusion in this area of the aquifer.

5.5 The effect of removing distribution constraints on the operation of the LCUS system may result in increased availability of water for supply. This would need to be simulated using the MOSPA model and should follow any coupled groundwater and surface water hydrological modelling, as this may indicate a need for more detailed representation of the borehole groups in MOSPA. The sequence of returning to sources within the LCUS for extra water at high demand periods also requires further modelling work.

5.6 It is proposed to carry out investigations to meet the following overall objectives:-

* to develop a clear management policy for sustainable use of the groundwater resources of the Fylde aquifer and surface waters of the Wyre catchment, having regard to existing water users and the wider environmental concerns

* to enable recommendations to be made on the use of LCUS resources in meeting National Water Resources Strategy and other stakeholders requirements

* to identify and evaluate options to alleviate low flow problems in the Wyre catchment

5.7 Initially, the specific objectives of the studies are :-

- to re-assess groundwater recharge mechanisms
- to re-evaluate the availability of groundwater resources
- to model the groundwater/surface water interaction and the effect of groundwater abstractions on surface water and groundwater dependant environmental features
- to review the need for an additional data gathering programme
- to assess operational experience
- to review licence conditions
- to re-evaluate the yield/availability of supply of the LCUS system
- to evaluate schemes to alleviate low flow conditions

followed by further studies:

- to consider an environmental assessment and habitat audit of the affected catchments
- to assess the needs for improvements to fisheries
- to assess the economic benefits and consequences of recovery from any proposed changes

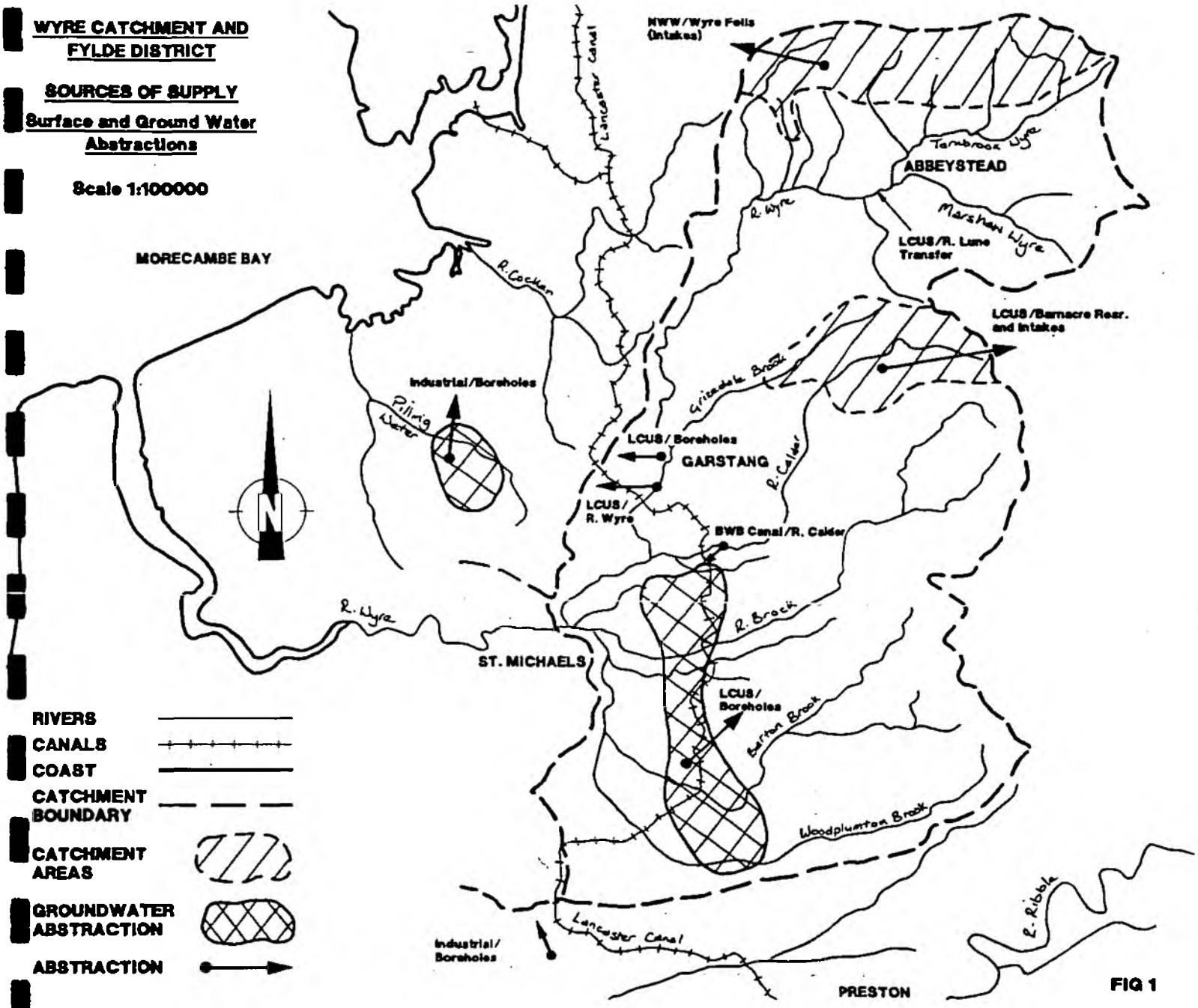
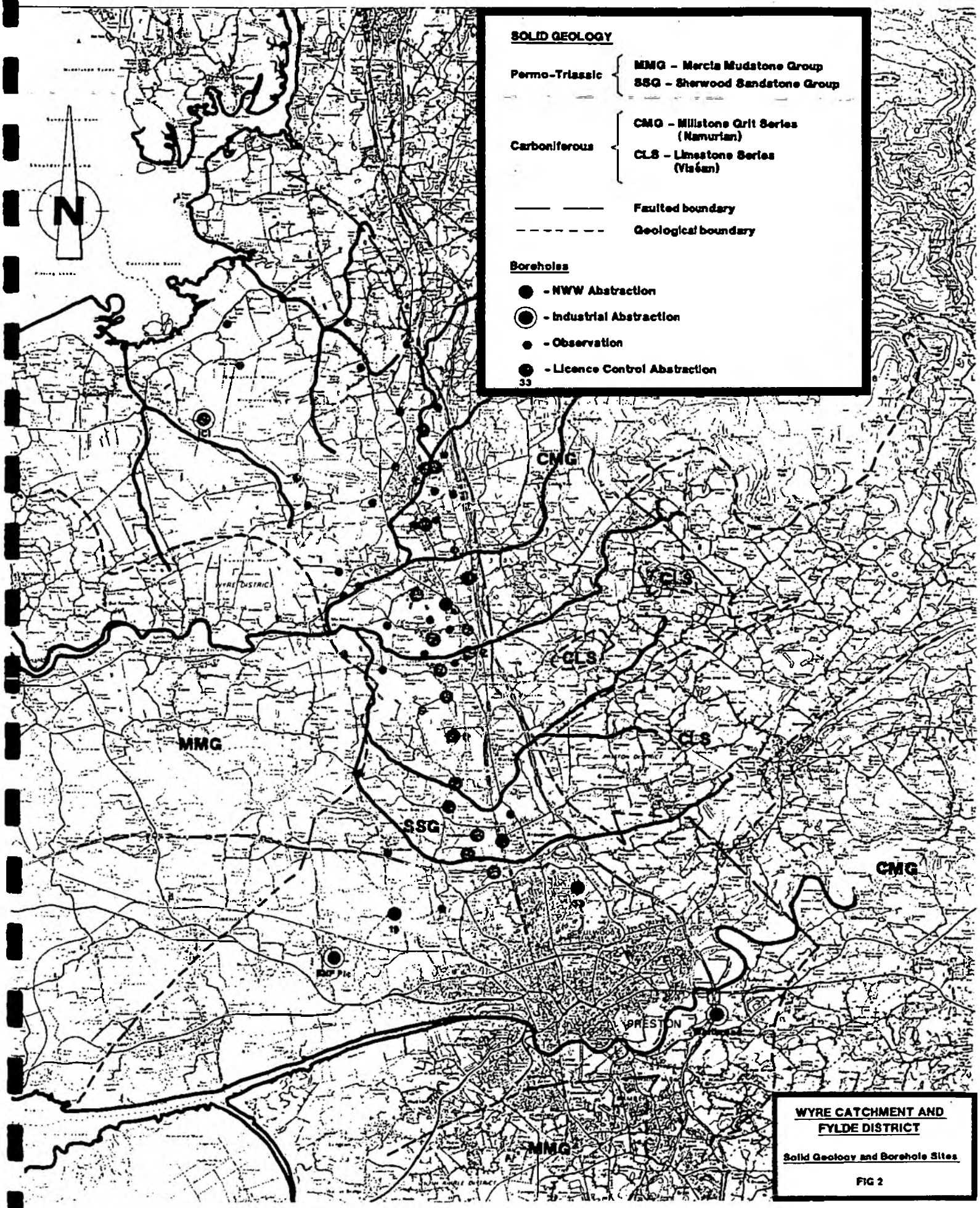

WYRE CATCHMENT AND FYLDE DISTRICT
SOURCES OF SUPPLY
Surface and Ground Water Abstractions
Scale 1:100000
MORECAMBE BAY
NWW/Wyre Falls (Intakes)
Lancaster Canal
Tarnbrook Wyre
ABBEYSTEAD
R. Wyre
Marshaw Wyre
LCUS/R. Lune Transfer
R. Cocker
LCUS/Barnacre Resr. and Intakes
Grizedale Brook
Industrial/Boreholes
Pilling Water
LCUS/Boreholes
GARSTANG
R. Calder
LCUS/ R. Wyre
BWB Canal/R. Calder
R. Brock
R. Wyre
ST. MICHAELS
LCUS/ Boreholes
Barton Brook
Woodplumton Brook
Lancaster Canal
Industrial/ Boreholes
R. Ribble
PRESTON
N
RIVERS
CANALS
COAST
CATCHMENT BOUNDARY
CATCHMENT AREAS
GROUNDWATER ABSTRACTION
ABSTRACTION

FIG 1



WYRE CATCHMENT AND FYLDE DISTRICT

Solid Geology and Borehole Sites

FIG 2

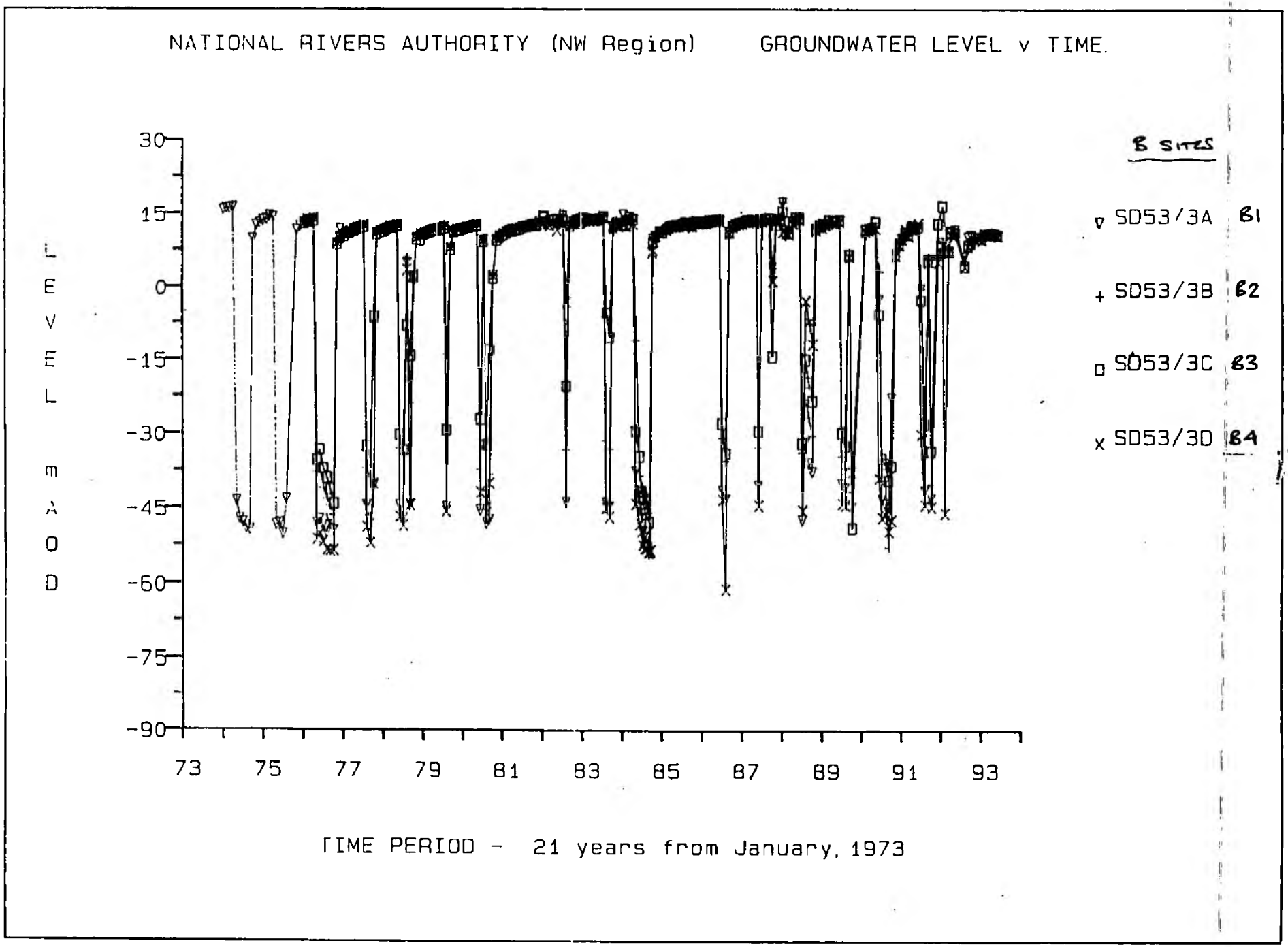

NATIONAL RIVERS AUTHORITY (NW Region) GROUNDWATER LEVEL v TIME.
LEVEL m AOD
30
15
0
-15
-30
-45
-60
-75
-90
73
75
77
79
81
83
85
87
89
91
93
TIME PERIOD - 21 years from January, 1973
B SITES
SD53/3A B1
SD53/3B B2
SD53/3C B3
SD53/3D B4

FIG 3A

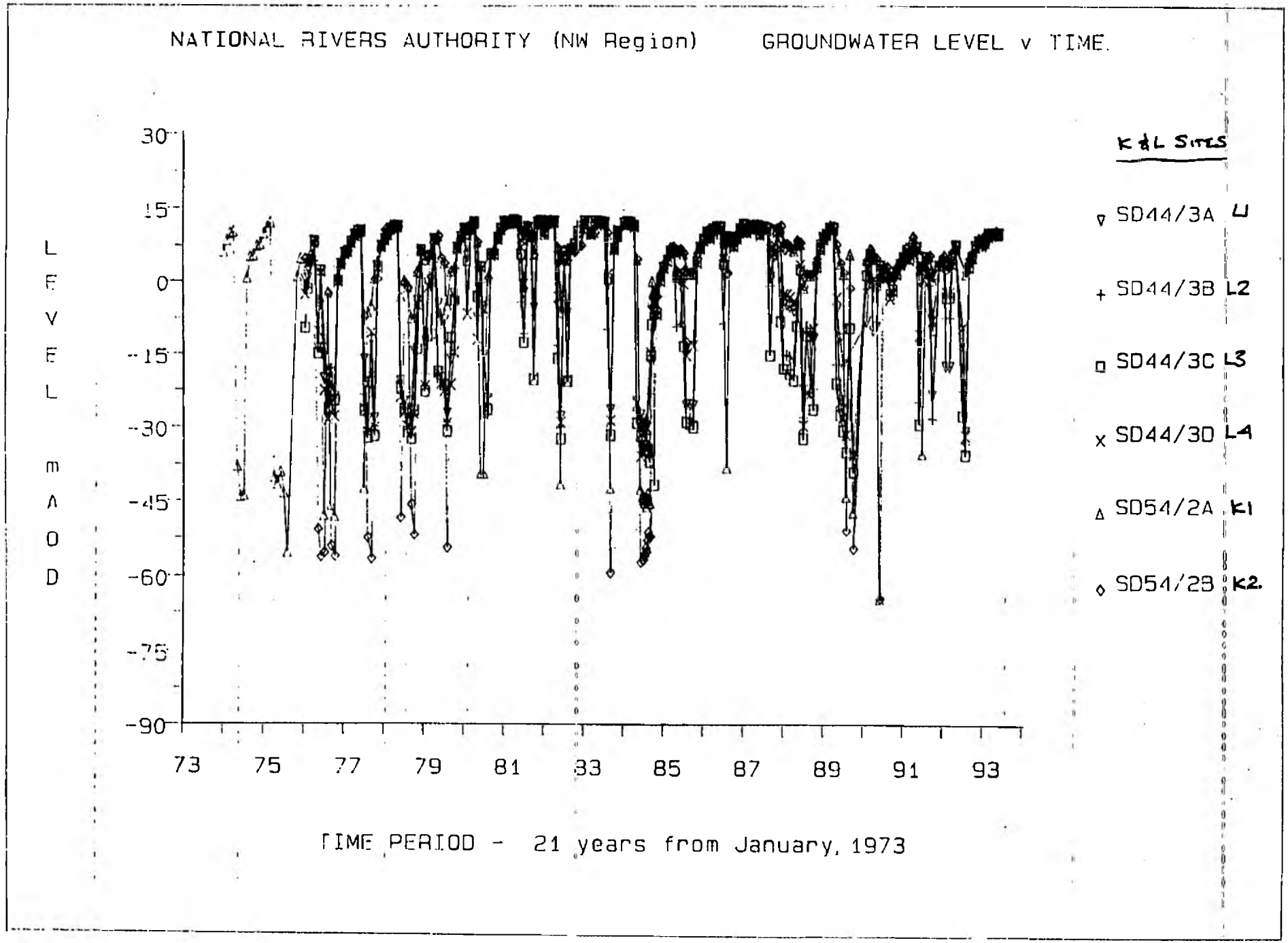

NATIONAL RIVERS AUTHORITY (NW Region) GROUNDWATER LEVEL v TIME.
LEVEL m AOD
30
15
0
-15
-30
-45
-60
-75
-90
73
75
77
79
81
83
85
87
89
91
93
TIME PERIOD - 21 years from January, 1973
K & L SITES
SD44/3A L1
SD44/3B L2
SD44/3C L3
SD44/3D L4
SD54/2A K1
SD54/2B K2.

FIG 3B

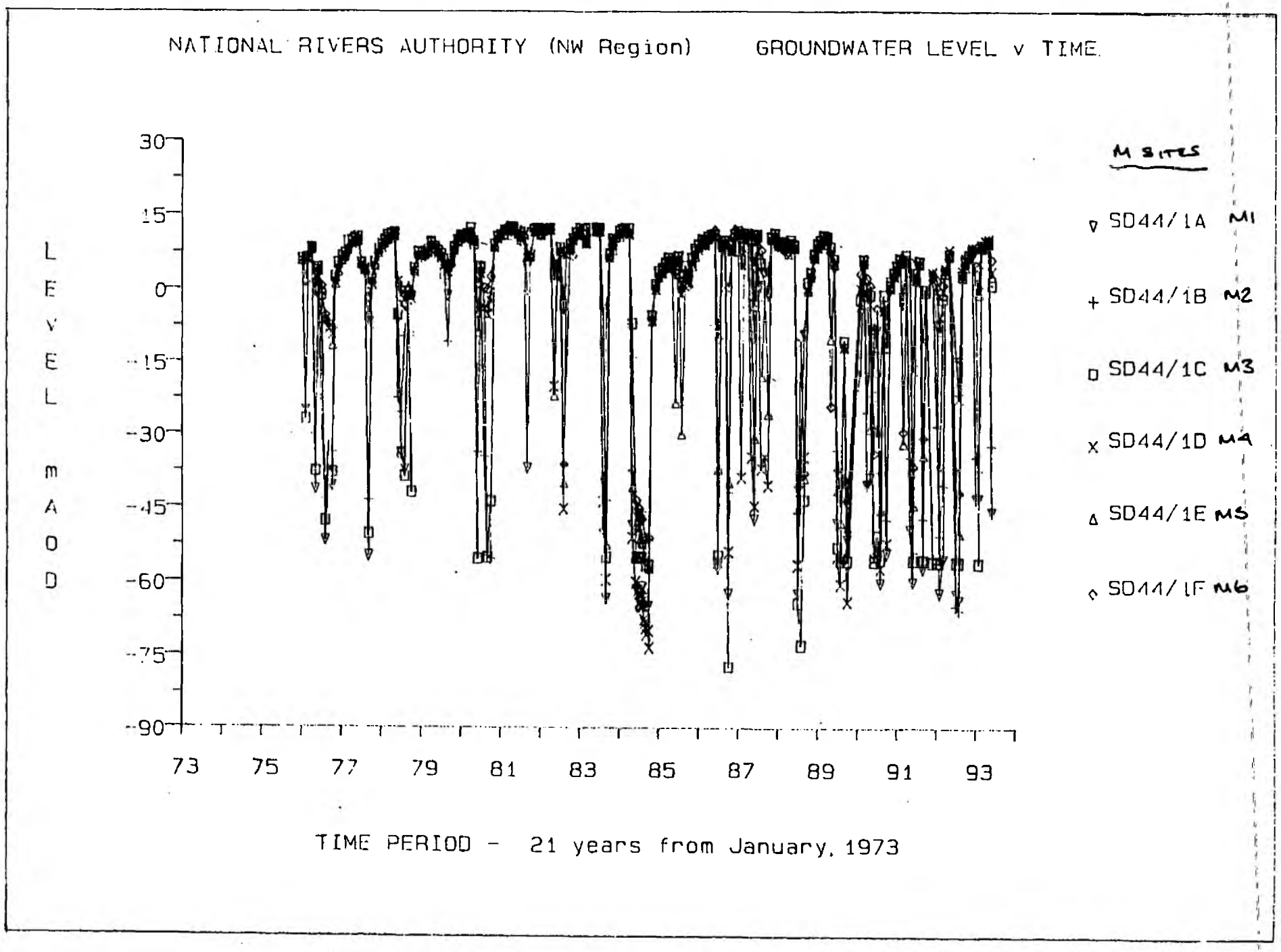

NATIONAL RIVERS AUTHORITY (NW Region) GROUNDWATER LEVEL v TIME
LEVEL m AOD
30
15
0
-15
-30
-45
-60
-75
-90
73
75
77
79
81
83
85
87
89
91
93
TIME PERIOD - 21 years from January, 1973
M SITES
SD44/1A M1
SD44/1B M2
SD44/1C M3
SD44/1D M4
SD44/1E M5
SD44/1F M6

FIG 3C

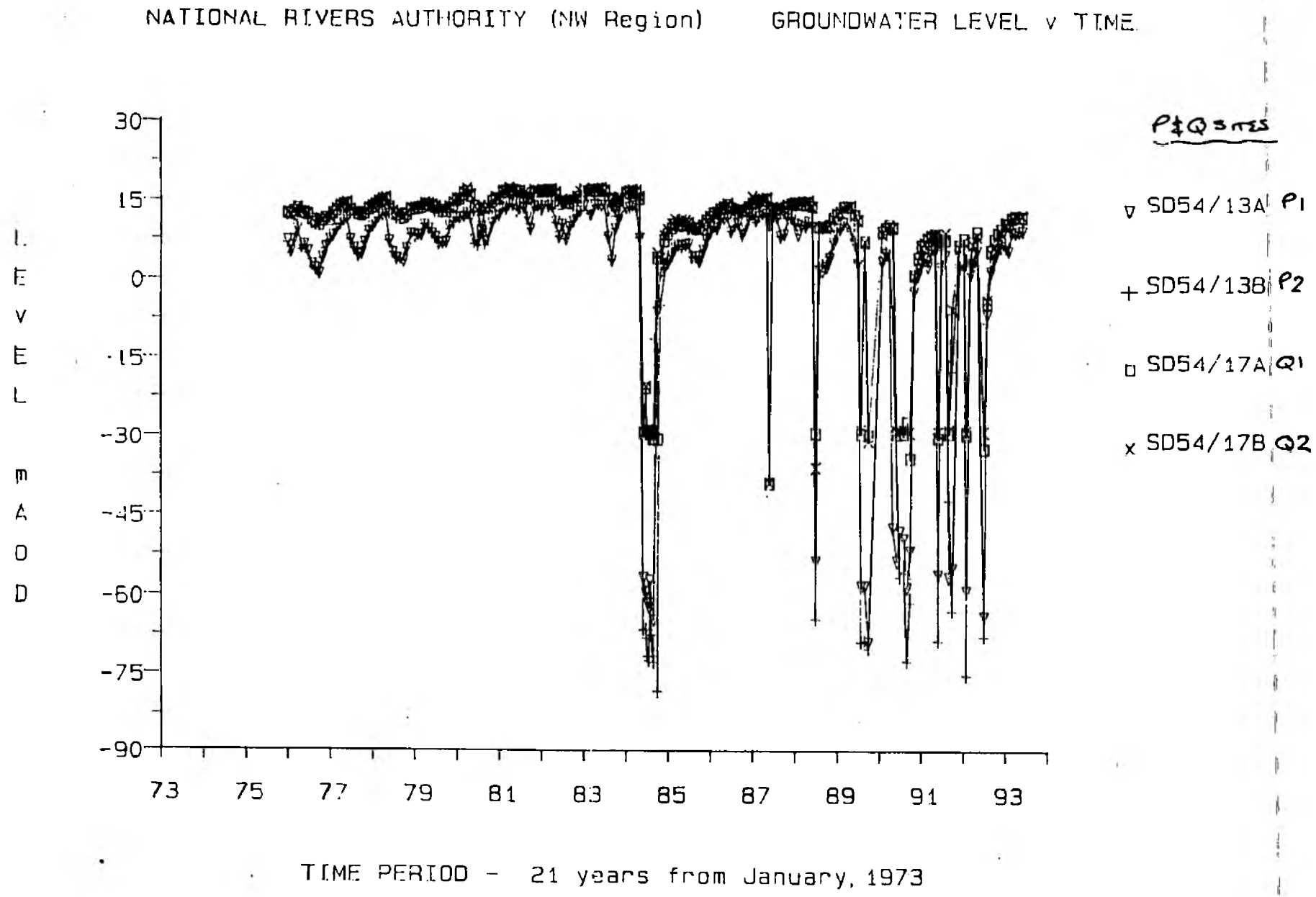

NATIONAL RIVERS AUTHORITY (NW Region)
GROUNDWATER LEVEL v TIME
LEVEL m AOD
30
15
0
-15
-30
-45
-60
-75
-90
73
75
77
79
81
83
85
87
89
91
93
TIME PERIOD - 21 years from January, 1973
P&Q sites
SD54/13A P1
SD54/13B P2
SD54/17A Q1
SD54/17B Q2

FIG 3D

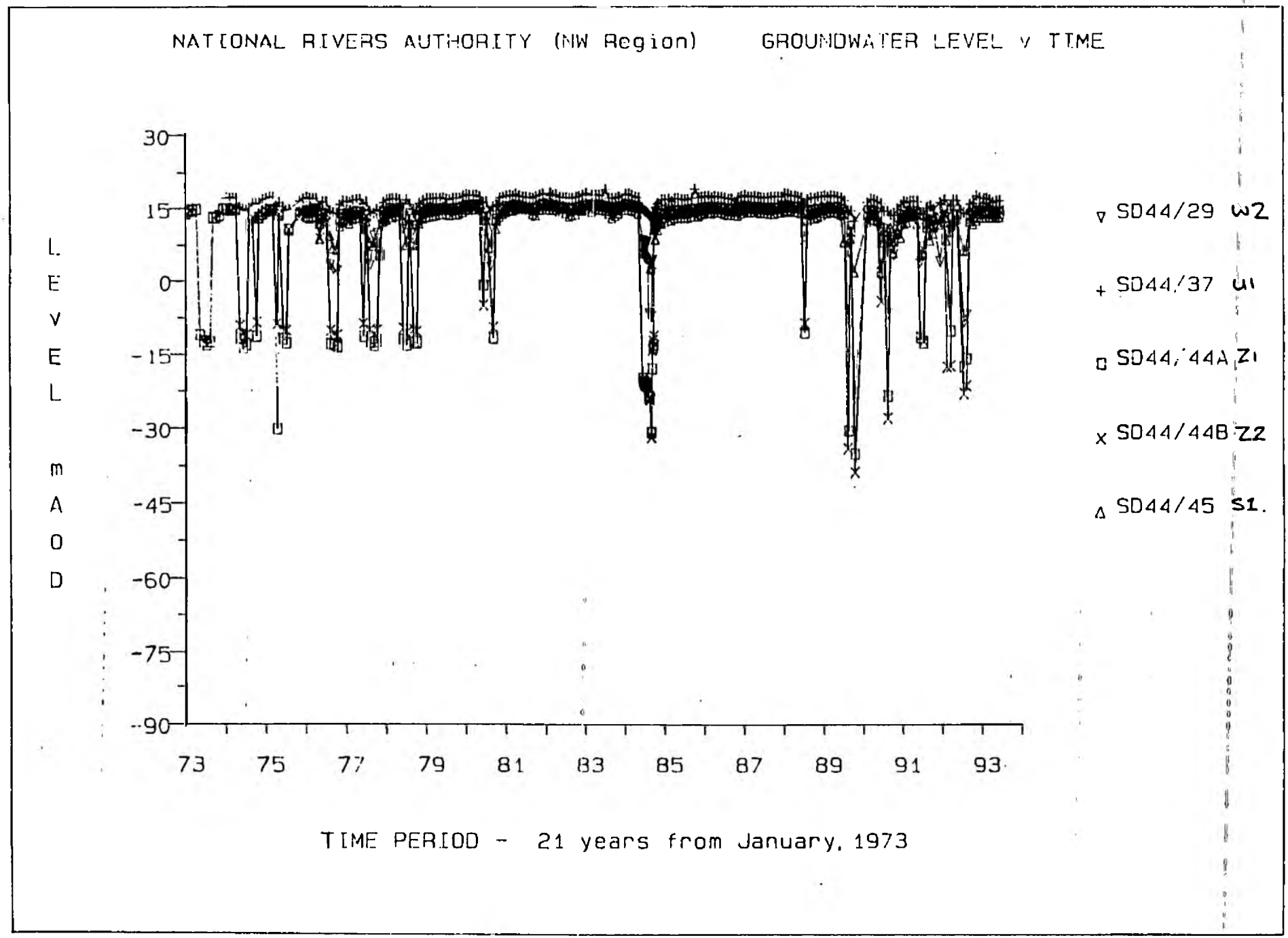

NATIONAL RIVERS AUTHORITY (NW Region) GROUNDWATER LEVEL v TIME
LEVEL m AOD
30
15
0
-15
-30
-45
-60
-75
-90
73
75
77
79
81
83
85
87
89
91
93
SD44/29 W2
SD44/37 U1
SD44/44A Z1
SD44/44B Z2
SD44/45 S1.
TIME PERIOD - 21 years from January, 1973

FIG 3E

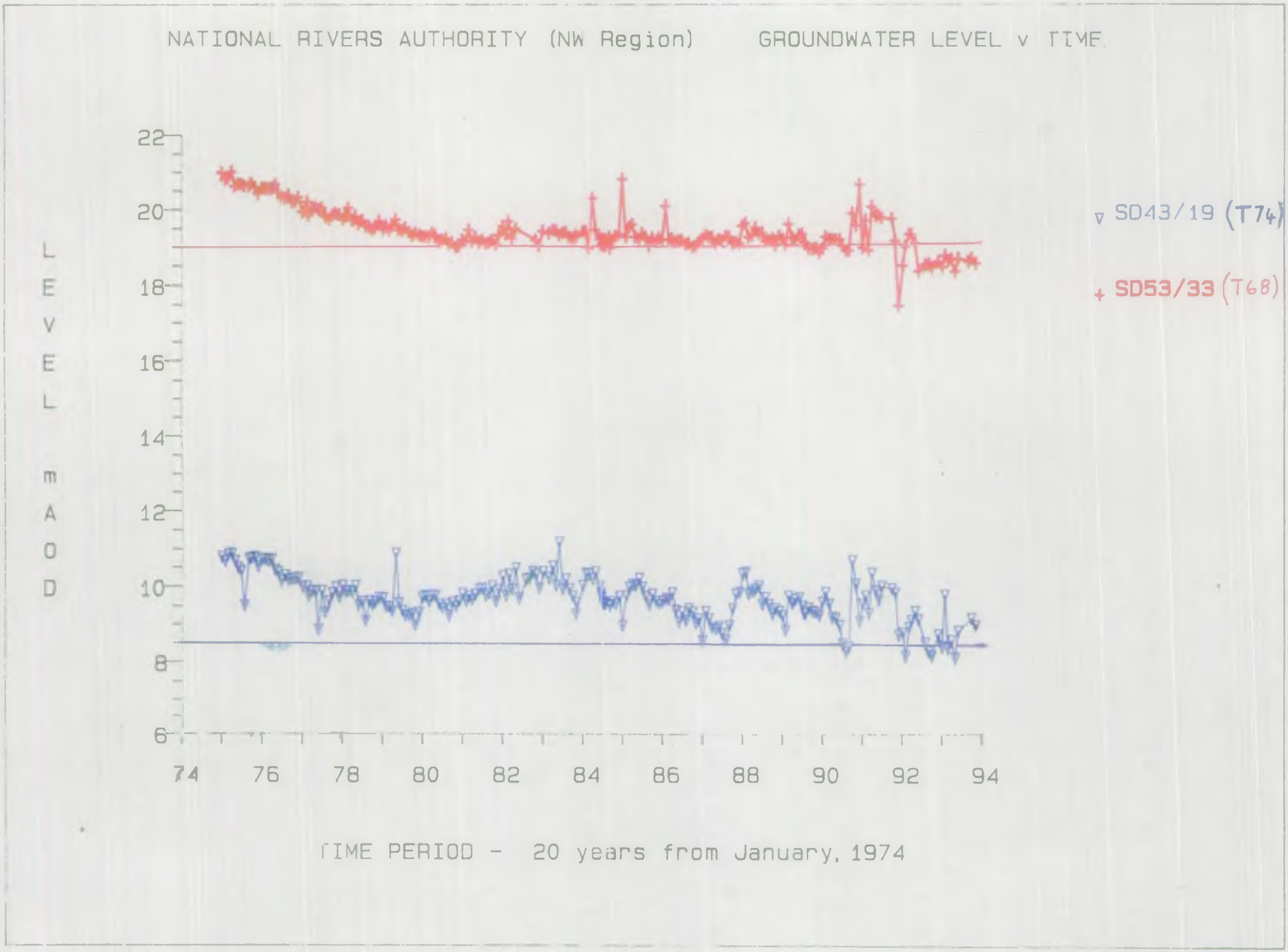

NATIONAL RIVERS AUTHORITY (NW Region) GROUNDWATER LEVEL v TIME
LEVEL m AOD
22
20
18
16
14
12
10
8
6
74
76
78
80
82
84
86
88
90
92
94
SD43/19 (T74)
SD53/33 (T68)
TIME PERIOD - 20 years from January, 1974

FIG 4

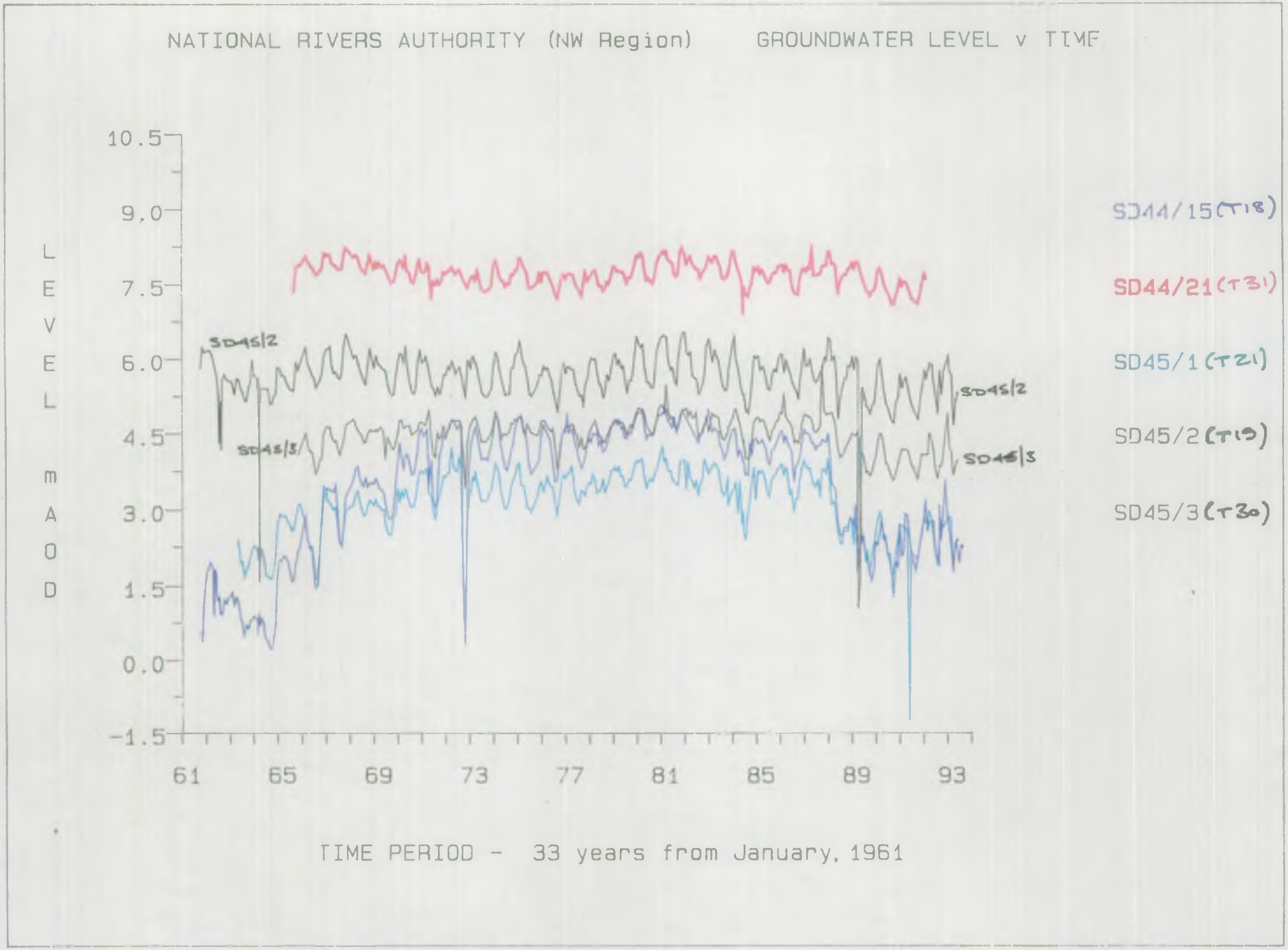

NATIONAL RIVERS AUTHORITY (NW Region)
GROUNDWATER LEVEL v TIME
LEVEL m AOD
10.5
9.0
7.5
6.0
4.5
3.0
1.5
0.0
-1.5
61
65
69
73
77
81
85
89
93
SD44/15 (T18)
SD44/21 (T31)
SD45/1 (T21)
SD45/2 (T19)
SD45/3 (T30)
SD45/2
SD45/3
SD45/2
SD45/3
TIME PERIOD - 33 years from January, 1961

FIG 5

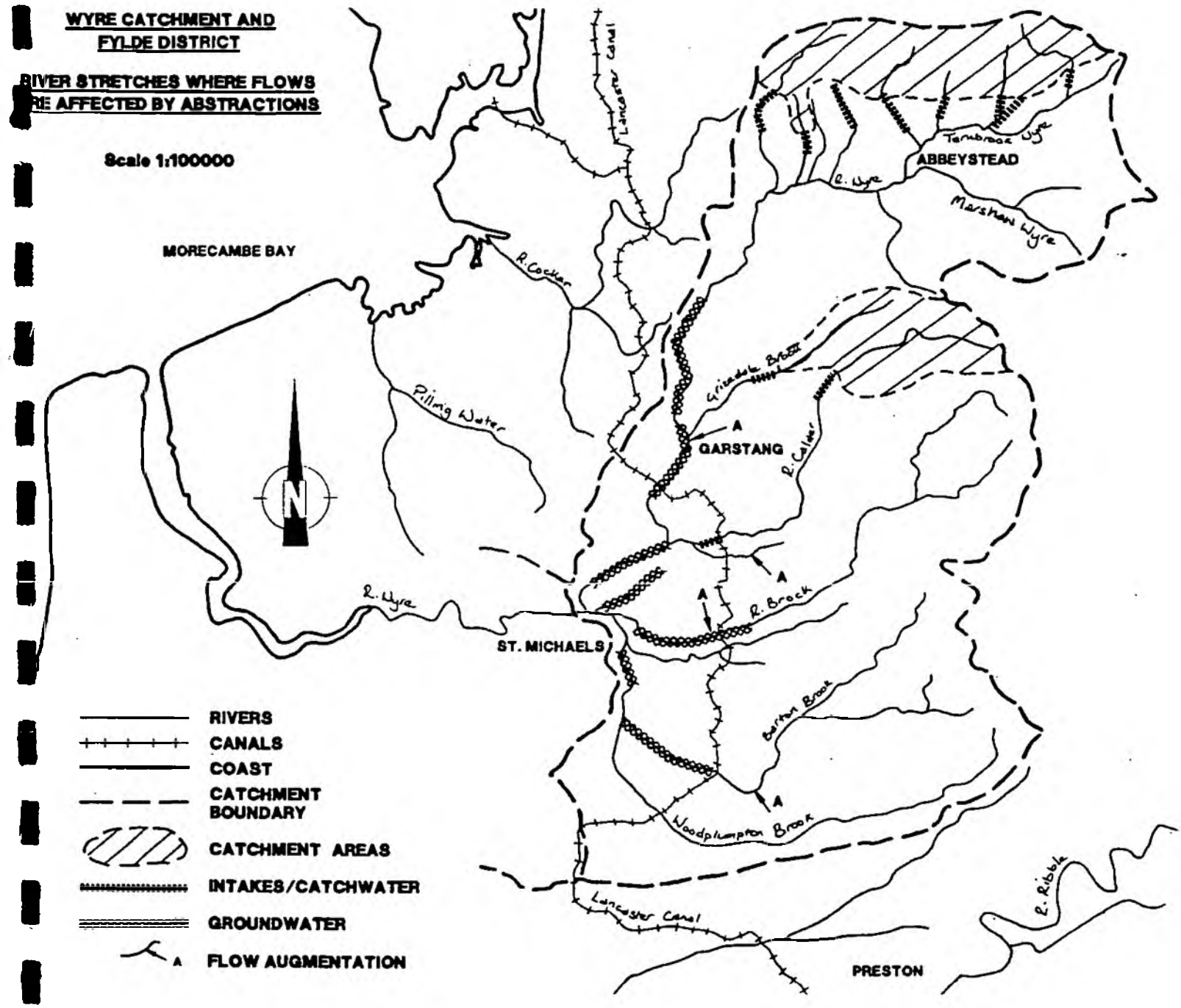

WYRE CATCHMENT AND
FYLDE DISTRICT
RIVER STRETCHES WHERE FLOWS
RE AFFECTED BY ABSTRACTIONS
Scale 1:100000
MORECAMBE BAY
Lancaster Canal
R. Cocker
Pilling Water
Grizedale Brook
GARSTANG
R. Calder
R. Wyre
ST. MICHAELS
R. Brock
Barton Brook
Woodplumpton Brook
Lancaster Canal
PRESTON
R. Ribble
Tarnbrook Wyre
ABBEYSTEAD
Marshaw Wyre
N
RIVERS
CANALS
COAST
CATCHMENT BOUNDARY
CATCHMENT AREAS
INTAKES/CATCHWATER
GROUNDWATER
A FLOW AUGMENTATION

FIG 6

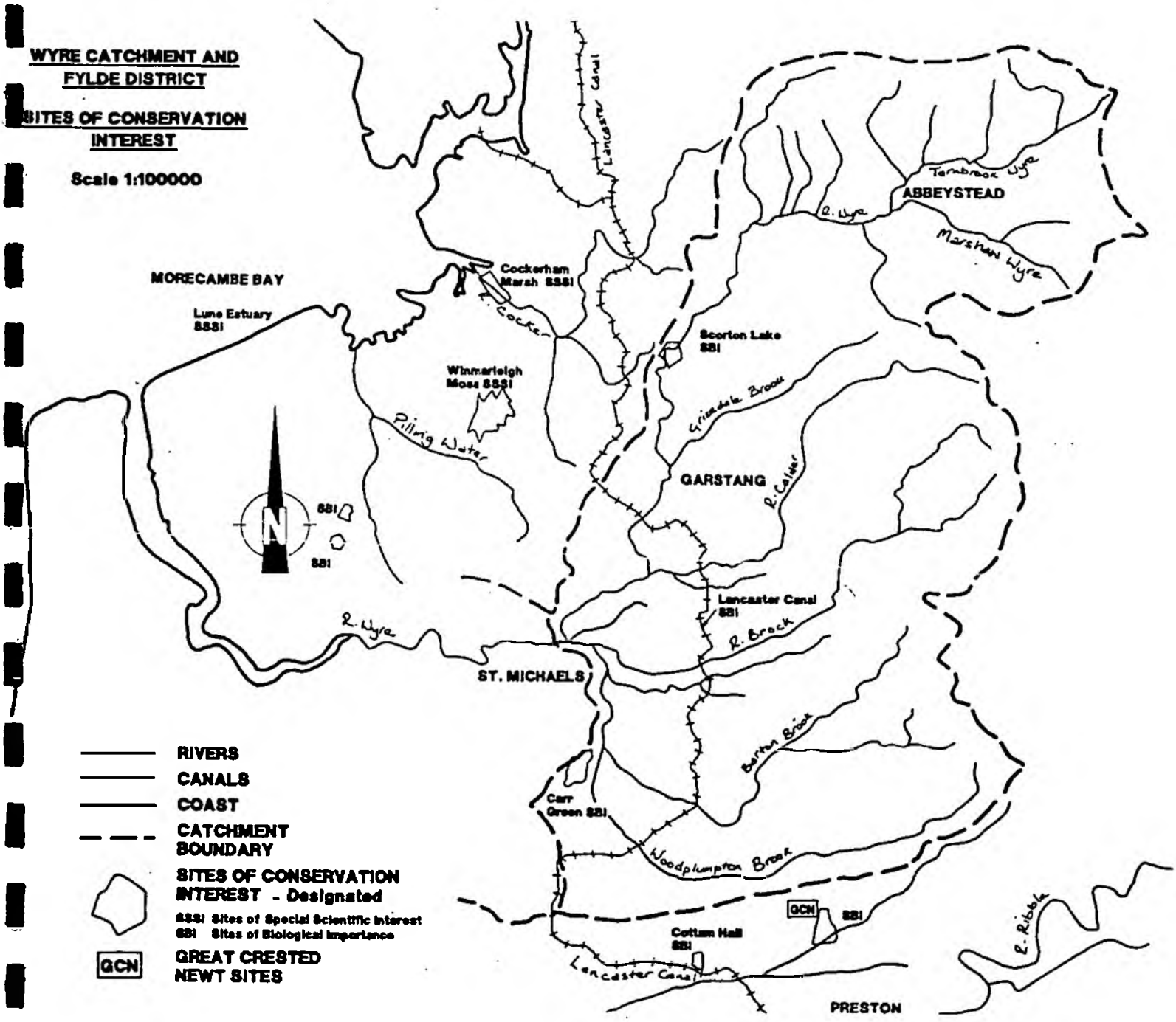

WYRE CATCHMENT AND
FYLDE DISTRICT
SITES OF CONSERVATION
INTEREST
Scale 1:100000
MORECAMBE BAY
Lune Estuary
SSSI
Cockerham
Marsh SSSI
Winmarleigh
Moss SSSI
Scorton Lake
SSI
Lancaster Canal
Tambrook Wyre
ABBEYSTEAD
R. Wyre
Marshaw Wyre
R. Cocker
Pilling Water
Grizedale Brook
GARSTANG
R. Calder
SSI
SSI
N
Lancaster Canal
SSI
R. Brock
R. Wyre
ST. MICHAELS
Barton Brook
Carr
Green SSI
Woodplumpton Brook
GCN
SSI
Cottam Hall
SSI
Lancaster Canal
R. Ribble
PRESTON
RIVERS
CANALS
COAST
CATCHMENT
BOUNDARY
SITES OF CONSERVATION
INTEREST - Designated
SSSI Sites of Special Scientific Interest
SSI Sites of Biological Importance
GCN
GREAT CRESTED
NEWT SITES

FIG 7

APPENDIX A

ECONOMIC EVALUATION OF LAKE VYRNWY WITHIN THE INTEGRATED WATER SUPPLY SYSTEMS OF NORTH WEST WATER

Economic Evaluation of Lake Vyrnwy within the Integrated Water Supply Systems of North West Water

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S Walker BSC, PhD, CEng, MICE (Fellow**)
T Wyatt BSc, ***

ABSTRACT

In 1992, the National Rivers Authority (NRA) published a discussion document on the National Water Resource Strategy highlighting the future probability of supply deficits in the south east and surpluses in the north and west of England and Wales. One suggestion for rectifying this imbalance was to divert water from Vyrnwy, at present used by North West Water Ltd (NWW) for direct supply to Liverpool, and release it to regulate the River Severn, for onward transfer to the Thames. Joint investigations by the NRA and North West Water have been taking place to establish the implications to North West Water's existing water resources and water supply systems of Vyrnwy redeployment.

The studies involved consideration of the relationship between increased regulation releases and direct supply rates from Vyrnwy; the investment and long-term operating cost implications of replacing Vyrnwy supplies either by sources within NWW's Southern Command Zone system or by transfers from NWW's Northern Command Zone; and potential operational difficulties.

The paper describes the way in which each of these aspects has been addressed. The results demonstrate the necessity of evaluating Vyrnwy as a component of the integrated water supply systems of NWW and of those in other parts of the country, if optimal use is to be made of water resources in the future.

Key Words: demand, modelling, operating costs, optimisation, regulation, reliability, reservoir, resource availability, simulation, Vyrnwy

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VYRNWY RESERVOIR

BACKGROUND

Vyrnwy Reservoir in mid-Wales is located on Afon Vyrnwy, a headwater of the River Severn. It was built by Liverpool Corporation in 1892 primarily to meet the growing water demand of Liverpool. In addition, numerous small supplies serve parts of mid-Wales and Cheshire along the line of the Vyrnwy aqueduct. Direct supplies are abstracted at Vyrnwy and gravity feed the Oswestry Water Treatment Works. From Oswestry to the terminal storage at Prescot in Liverpool, a distance of 80 km, the Vyrnwy aqueduct comprises three pipelines. The gravity capacity is estimated to be 173 Mld with maximum throughput rising to 253 Mld if two of the lines are boosted at Bickerton, Norton and Cuerdley.

Under the 1974 water industry reorganisation, ownership of Vyrnwy passed to Severn Trent Water who currently operate the reservoir. The abstraction licence is held by North West Water. The gross capacity of Vyrnwy is 59,666 Ml. and the net direct supply yield is 220 Mld[1] based on 2% reliability and a policy which requires the reservoir to refill at least once in five years[2]. The current direct supply capacity is limited to 200 Mld by the effective transfer capacity between the reservoir and Oswestry Treatment Works. There is a statutory compensation release requirement of 45.64 Mld. In addition, a Water Bank of 5800 Ml contributes releases to help regulate the flows in the River Severn at Bewdley. On the first day of each month from March to October, 725 Ml is added to the water bank. Water is then released to help support the maintained flow in the Lower Severn. In maintaining the flows in the River Severn, releases from Vyrnwy are linked to the operation of the Shropshire Groundwater Scheme and Clywedog reservoir in mid-Wales. The pattern of regulation releases varies considerably from year to year.

SOUTHERN COMMAND ZONE

As shown in Fig 1, the Southern Command Zone comprises, Vyrnwy, the Rivington reservoirs, abstractions from the River Dee, numerous groundwater sources and bulk supplies from the Northern Command Zone. The Southern Command Zone sources supply a population of around 2.7 million in Merseyside and Cheshire, with an average of 900 Mld on average.

The net yield of Rivington reservoirs is 49 Mld[1] and the Treatment Works has a capacity of 80 Mld. Water is fed 28 km by a gravity pipeline to Prescot.

North West Water abstracts water from the River Dee at Huntington, from the River Dee to Sutton Hall on the Wirral, and via the Llangollen Canal to the Hurleston Treatment Works. The combined, licence covering all three sites, allows abstraction of 650 Mld subject to adequate flow in the river at Chester Weir.

Within the Southern Command Zone there are eight groups of boreholes. Concerns about long term depletion of groundwater levels, saline intrusion and potential nitrate contamination have led to target abstractions significantly below licensed quantities. Daily abstractions are limited to 250 Ml with the annual average restricted to the equivalent of 171 Mld.

Water originating in the Southern Command Zone can be supplemented by supplies from the Lake District resource system via the Thirlmere Aqueduct. On average, some 54 Mld is transferred from the Northern to the Southern Command Zone.

NATIONAL WATER RESOURCES DEVELOPMENT STRATEGY

In 1992, the NRA produced a discussion document which highlighted concerns about potential supply shortfalls in the south and east of England by the year 2021[3]. Based on the information available at the time, public water supply demand projections indicated increases up to 45% compared with 1990 levels. This suggested that, whilst there is currently a surplus of supplies in the south east of England, even with the construction of already planned new resource systems by 2021, there will be a significant shortfall in resource availability. The report gave preliminary consideration to how this imbalance may be met, including some options which involved inter-regional transfers. Since demand projections for public water supplies in the north west were showing a reduction in demand in 2021 compared with the current situation, indicating a potential surplus into the next century, one of the examples considered was the redeployment of Vyrnwy to regulate the River Severn rather than being used to serve Liverpool. The increased regulation of the Severn would allow increased abstractions in the lower Severn to meet demands either in the West Midlands or to allow onward transfer into the Thames catchment.

Following publication of the report, it was necessary to refine the information presented on resource availability and demand projections so that the NRA could produce a national water resource development strategy. As part of this initiative, a joint investigation by the NRA (NW Region) and North West Water was instigated to consider the water resource implications for the region, possible alternative source of supply to meet any shortfall caused by Vyrnwy redeployment, and the costs of any associated engineering works.

Before a Vyrnwy scheme is promoted, it is important to ensure that demand forecasts and resource assessments within the NW stand scrutiny. This includes the need for adequate resources to alleviate low flow problems within the Region, since at several locations, environmental damage has occurred because abstraction licence conditions have, in the past, been too generous. Abstractors, acting entirely within their legal entitlement, cause low flows and even dry up some rivers under certain weather conditions. This is because when the original abstraction conditions

were set, the needs of the environment were not as well understood or had as high a priority as today. The NRA has a programme to ameliorate these situations where it is cost beneficial and practical to do so.

To allow a valid national comparison of strategies, it is necessary to calculate the marginal cost of water supplied at the point of delivery.Such investigations have involved consideration of the relationship between increased regulation releases and direct supply rates from Vyrnwy, and an assessment of the investment and long term operating cost implications of replacing Vyrnwy supplies by increased abstractions from the River Dee at Huntington and borehole sources within the Southern Command Zone. Consideration has also been given to the implications of supplementing Southern Command Zone supplies by increased bulk supplies from the Northern Command Zone and the requirement to develop new resources. Particular attention has been given to the operational implications associated with Vyrnwy redeployment. For example, by looking at how the pattern of demand may be met on a day by day basis, and the potential difficulties arising from increased reliance on river abstractions which are, from time to time, subject to disruption on account of pollution incidents.

OPTIONS CONSIDERED

In determining the need for alternative supplies to be provided in the Southern Command Zone area a number of scenarios for the direct supply rates from Vyrnwy were considered. The supply rates were 198, 173 (the gravity supply limit) 120, and 60 Mld. (Initially it was proposed that a complete redeployment of Vyrnwy be considered. However, this was discounted due to the need to maintain a minimum of 60 Mld to provide supplies to areas where no alternative supply was readily available.)

The most recent assessments of the viability of developing alternative major resources in north west England were carried out in 1976 and 1979. These studies considered promotion of schemes such as a barrage across Morecambe Bay, inland reservoirs on the Ribble, the Lune, and enlargement of Haweswater. At that time these schemes were rejected on environmental grounds, in the current work it was considered that these environmental objections had, if anything, strengthened and therefore the schemes were not considered to be viable alternatives.

Groundwater Development

In the Southern Command Zone, NWW abstracts an average of 163 Mld from the Triassic Sandstone aquifer of Cheshire. The NRA considers that the current level of abstraction is appropriate and any significant increase in the current level of abstraction is unlikely to be

acceptable. The possibility of increasing abstractions through the use of artificial recharge was investigated in 1979. By treating additional water taken from Vyrnwy in the winter months and using it for recharge purposes it was estimated that an increased summer groundwater abstraction of some 70 Mld. could be provided. There is, however, no experience of artificial recharge in the Triassic Sandstone or of the potential problems of recharging with treated water. Hence any proposals for artificial recharge would need significant further investigation.

River Dee supplies.

The major NWW supply source in the southern command zone is the River Dee. Although current licensed abstraction from the Dee, including an allowance for known developments by Welsh Water, Wrexham and East Denbighshire and Chester Water Company, is very close to the stated yield of the system, there is potential for development of the Dee system. As part of this study consideration was given to enlarging Brenig and utilising spills from Alwen to assist refill. This would increase the yield of the system by 60-75 Mld. Alternatively raising Brenig by 2.0 m. and Llyn Celyn by 1.5 m. would provide an increase of approximately 60 Mld.

Two options were considered for abstracting this additional yield. Firstly a scheme in the upper Dee with transfers to Oswestry Treatment works, which would have the advantage of reducing the risk of pollution problems in the Dee and allow the option of blending Dee and Vyrnwy water at Oswestry. Secondly an extension of the existing intake at Huntington and an increase in the treatment capacity of the works, and associated aqueduct capacities.

Development of Northern Command Zone sources.

The major sources in the Northern Command Zone are in the Lake District and the components of the Lancashire Conjunctive Use system which takes water from the rivers Lune and Wyre, groundwater from the Fylde area, and supplies from the upland reservoirs at Stocks and Barnacre. Peak output from the Lancashire Conjunctive Use scheme is currently restricted by limitations in the trunk main and aqueduct transfer capacities. If these constraints were removed an increase of some 80 Mld could be obtained. Additional capacity would also be required in the links between the Northern and Southern Command Zone systems if this additional supply is to be utilised in meeting deficiencies in the Southern Command Zone due to redeployment of Vyrnwy.

The River Ribble was identified as a potential new resource in 1970 but at that time raw water quality of one of the principal tributaries precluded development. However, significant improvements in quality have since been achieved and as part of this study a scheme which

abstracted water at Salmesbury for transfer to the Rivington reservoir complex has been considered. The scheme included for bankside storage on the Ribble to provide a buffer against potential pollution incidents on the river. The environmental impact of this scheme was considered to be the most significant of any of the schemes in the study and would require substantial further study if preferred on economic grounds.

The possible provision of additional supplies from the existing Lake District sources was also examined. However, as described in the following section, modelling of the Northern Command Zone showed that there was no significant additional supply available from these sources.

WATER RESOURCE SYSTEM MODELLING

Independent Operation of Vyrnwy with constant regulation releases.

Due to aqueduct capacity constraints, direct supplies from Vyrnwy are currently taken at or near to a constant rate of 200 Mld, which is close to the historic reliable yield of the reservoir net of daily compensation and regulation releases. If the minimum direct supply were to be significantly reduced as a result of increasing the amount of water to be made available for regulating the River severn, there would frequently be times when additional direct supplies could be abstracted without compromising regulation release reliability.

The MOSPA computer program developed by Water Systems Consultants (WSC) was used to simulate and optimise daily operation of Vyrnwy under different scenarios. The generalised nature of the program enables a water resource system, as well as the data to be employed, to be defined via a series of input files.

An initial run of the MOSPA program was made to determine the maximum constant supply rate that could have been maintained over the simulated sequence, subject to complying with the existing operating procedures and reliability criteria. This showed the historic maximum constant direct supply rate to be 198 Mld.

To determine the maximum regulation releases that could be maintained while complying with various direct supply rates, successive simulation runs were made varying the daily March - October water bank input / regulation release until the requisite reliability criteria was obtained.

Within the simulation model the quantity of water taken as direct supply is determined , on a daily basis, by the contents of the reservoir relative to a defined set of monthly retention levels.

To estimate the total direct supplies that would be available to North West Water under the various regulation release scenarios investigated, retention levels were optimized for each case. The optimizations were performed using the facilities incorporated in MOSPA for deriving multiple-regime operating policies which minimize long-term operating costs while satisfying defined reliability criteria. Using the optimised operating policies, simulations were then performed to estimate the direct supplies that would have been available to North West Water over the historic inflow sequence.

Evaluation of Vyrnwy supplies within North West Water's Southern Command Zone.

The value of Vyrnwy supplies within the southern command zone, and import requirements from the Northern Command Zone, were estimated using a MOSPA simulation model based on that previously constructed to investigate the operational performance of future developments of the system[5]. The purpose of these simulations was:

> To estimate the increase in variable operating costs that would arise from replacing direct supplies from Vyrnwy with supplies from other sources within the system
>
> In the case that demands could not be satisfied from sources within the Southern Command Zone , to estimate the level and temporal distribution of imports that would be required from the Northern Command Zone system.

During previous studies[5] it had been found that, after taking supplies from Vyrnwy and Rivington, southern command zone demands would be most economically met by abstracting additional quantities from the River Dee. It was also shown that, due to the low relative costs of Vyrnwy and Rivington water, optimum system operating policies were effectively determined by the retention levels applied to these two reservoirs.

Accordingly, analysis of the Southern Command Zone system was made using simulation in conjunction with the sets of retention levels derived when studying the independent operation of Vyrnwy under the various re-deployment scenarios described above, and no attempt was made to further optimize system level operating policies.

Outputs from the simulation model provided the daily pattern of any Northern Command Zone imports, and this information was used for the sizing of requisite transfer capacities between the two systems.

Estimation of the marginal costs of operating North West Water's Northern Command Zone system.

To estimate the cost of replacing Vyrnwy water from sources within the Northern Command Zone system, the study established the marginal costs associated with operating the Northern Command Zone over a range of demands. Analyses were also carried out in order to determine the maximum sustainable demand that can be met by the Northern Command Zone system. The results showed that:

- With historic monthly demand profiles the maximum demand that can be supplied by the Northern Command Zone system is some 890 Mld;

- if seasonal demand variations are ignored, the maximum sustainable supply from the system rises to some 930 Mld.

- at a demand level of 850 Mld, the marginal costs of supply are between £35 and £65 per Ml dependant on the reliability criteria applied.

Independent operation of Vyrnwy with varying regulation releases.

In assessing the modelling results outlined so far it is important to recognise that they assumed that Vyrnwy regulation releases would be taken at a constant rate in the months of March to October inclusive. Should Vyrnwy be partially redeployed, a more flexible regulation regime is more probable. Accordingly, the implications of varying the pattern of releases has been investigated based on four sets of compensation and regulation release time series provided by NRA - Severn Trent Region. These took the form of five day (pentad) values covering the historic period for a series of compensation and release requirements at varying minimum direct supply rates (MDSR's).

Initial simulation runs showed that, with these regulation demands, the associated minimum direct supply rates could only be maintained if non-utilised water bank contents could be carried over from one year to the next in accordance with current operational procedures[5]. However, provision of water bank storage volume equivalent to the maximum annual regulation release requirements would lead to highly inefficient operation in terms of increased flood releases and reduced ' non-firm' direct supplies.

	Daily Compensation (Ml/annum)	Regulation Releases (Ml/annum)			
		MDSR = 198	MDSR = 173	MDSR = 120	MDSR = 60
Maximum	16,025	5,815	12,235	23,290	40,825
Average	15,243	1,459	3,493	7,936	14,467
Minimum	14,328	0	0	0	0
Minimum required size of Water Bank (Ml)		5,815	8,950	12,995	19,062

Table I. Basic statistics of time series regulation demands and estimated minimum water bank storage volumes.

To investigate how water banks of such significant size might be operated, an enhanced MOSPA model of Vyrnwy was constructed. Using this model, the minimum required water bank sizes compatible with meeting the specified regulation releases and minimum direct supply rates and the appropriate reliability criteria were established. The resulting values are given in Table I.

As previously described, retention levels were optimized for the direct supply storage i.e. the gross storage volume of Vyrnwy less the assigned water bank capacity. Simulation with these operating policies produced the values of average total direct supplies shown in Fig 2, and it can be observed that these are significantly higher than those obtained when constant release rates were assumed. This clearly shows the value of developing an optimised operating strategy for the water bank. Further work will be necessary to develop optimized operation of Vyrnwy in conjunction with of the other Severn regulation reservoirs, the Shropshire Groundwater Scheme and the River Dee.

Comparison of Options

The results from the modelling work indicated that with the current treatment capacity on the River Dee additional supplies would be required if the minimum direct supply rate from Vyrnwy were reduced to 120 Mld. If the River Dee treatment and distribution capacity were increased by 80 Mld, to the current licence maximum, then additional supplies would not be required until the direct supply from Vyrnwy were reduced to 60 Mld. As previously indicated the daily

average and the maximum requirement for additional supplies obtained from the modelling were used to size the components for resource development.

All of the engineering works included in the options considered were costed at a preliminary estimate level and operating costs either estimated or derived from the use of the optimisation and simulation models. These costs were combined in net present value calculations based on 6% and 10% discount rates. The most economic option for a firm supply from Vyrnwy of 180 Mld is increased utilisation of groundwater within the Southern Command Zone. For a minimum direct supply of 120 Mld the preferred option would be an upper Dee abstraction of approximately 50 Mld. This is also the preferred solution with a minimum direct supply rate of 60 Mld.

The capital costs involved in the options considered varied between £16 million and £68 million and increased operating costs varied between £0.2 million and £3.7 million per annum. Combining these costs as net present values indicates the cost to the North West region of replacing 60 Mld is approximately £0.4 million per megalitre and the cost of replacing 120 Mld is approximately £0.35 million per megalitre based on a 6% discount rate and a 30 year period.

NRA NATIONAL STRATEGY

In March 1994, the NRA published its environmentally sustainable water resources development strategy for England and Wales [4]. This followed the collation and interpretation of the results outlined in this paper together with those from similar investigations in other parts of the country.

This report indicated that the projected fall in demand in the North West would not be as great as previously anticipated. Within the NRA discussion document, the projected surplus in the north west depended heavily on such a fall together with a successful leakage control policy by North West Water. In contrast, the demand predictions for the south and east were unlikely to reach the levels proposed in the 1992 document.

The report shows that partial redeployment of Vyrnwy will only be required should there be a moderate or high increase in demand nationally. The NRA believes that demand can be managed by the use of measures to control waste and consumption so that the need to redeploy Vyrnwy or develop other strategic resources can be postponed for 20 years or more. This provides an opportunity, before any strategic developments are commissioned, to fully assess the environmental impacts and economic costs of alternative developments, including

those that involve Vyrnwy redeployment. This implies a need to further extend the investigations into Vyrnwy redeployment within a national context.

CONCLUSIONS

Revised demand forecasts mean that the surplus of supplies within the north west would be less than previously estimated. Indications are that the potential for reduction in demand may have been over optimistic in the previously published figures. Demand predictions for the south and east parts of the country suggest that the increase in demand in these areas is likely to be less than originally anticipated, especially if the opportunities for demand management are taken.

In assessing regional surplus and deficits, it is not sufficient to consider only long term average demands and resources. Consideration needs to be given to the pattern of demand through the year since such variations significantly reduce the resource surplus in the north west. In estimating availability, an assessment is necessary of the resource requirements to overcome regional low flow problems. The assessment of regional balances must also allow for sufficient spare capacity to cater for a substantial maintenance programme, eg aqueduct and reservoir refurbishment. A minimum direct supply of 60 Mld must be maintained through the Vyrnwy aqueduct to maintain rural supplies. This means that total redeployment of Vyrnwy is not a workable option.

At current demand levels, any diversion of Vyrnwy water out of the region must be made up from alternative sources, in order to maintain security of supplies. This will incur significant capital and operating costs within the region as well as delivery costs to the South East.

In order to limit the requirement for alternative sources, the use of Vyrnwy must be fully optimized within any national resource grouping and ,in particular, in conjunctive use with the other Severn regulation reservoirs, the Shropshire Groundwater scheme and the River Dee.

In summary, the investigations so far carried out indicate that the potential surplus resources in the NW, identified in the 1992 discussion document, were over optimistic. Whilst there may be a modest amount of water available at Vyrnwy for transfer to the south east at certain times of year, the total redeployment of Vyrnwy will not be a practicable option. Options to replace Vyrnwy supplies within the north west region would raise significant environmental questions and involve substantial capital investment. In order to reduce the need for replacement resources the investigation of conjunctive operation of Vyrnwy alongside other existing

resources should continue. In a national context it is anticipated that demand can be sufficiently managed to postpone the need for any strategic development for at least 20 years. This gives the opportunity to further refine the work outlined in this paper to fully address the environmental issues, the water resources implications and the economic cost of any strategic option that involves partial redeployment of Vyrnwy.

ACKNOWLEDGEMENTS

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Southern Sources of North West Water

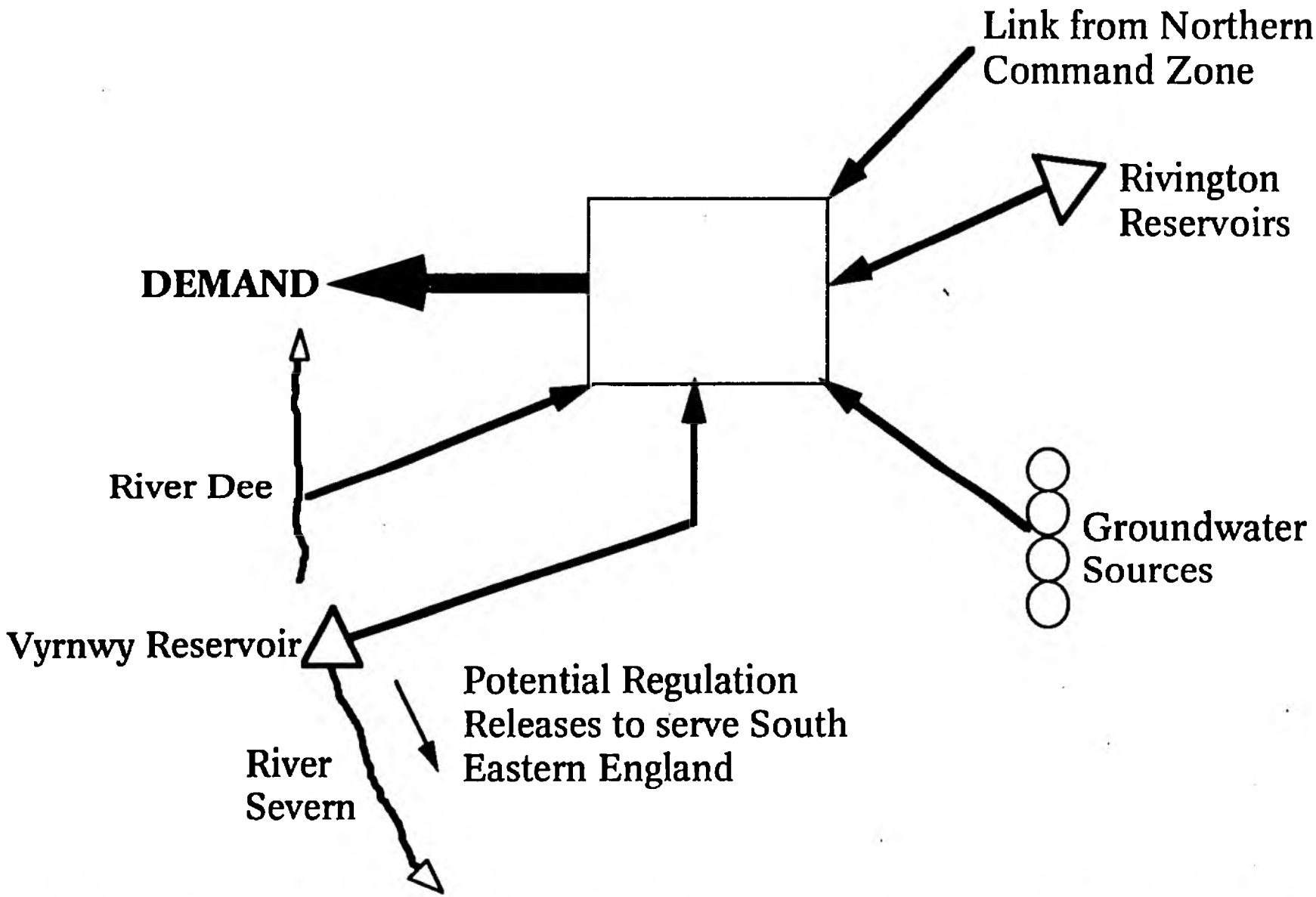
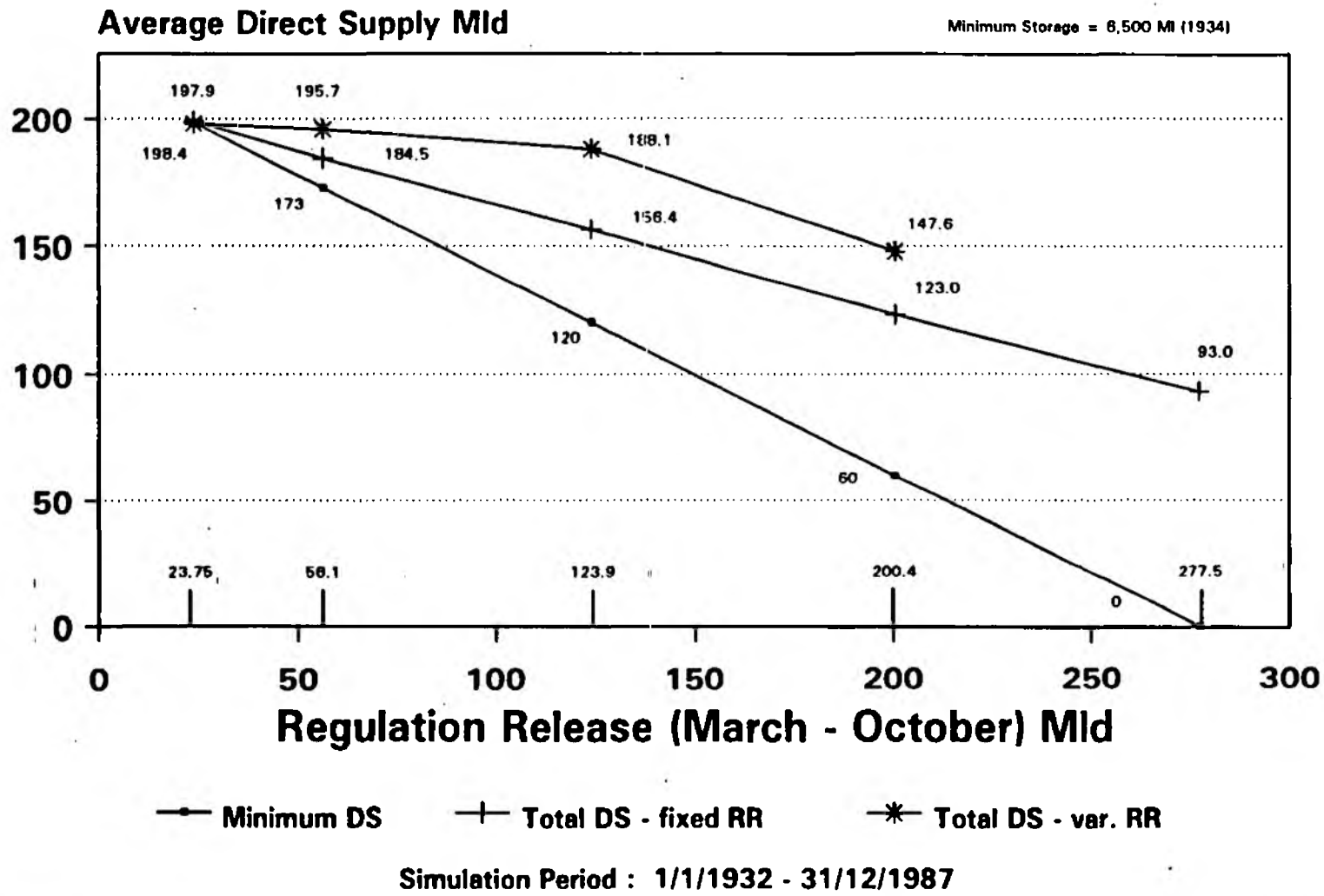


Figure 1

SIMULATED DAILY OPERATION OF LAKE VYRNWY
Direct Supplies vs. Water Bank Inputs



Simulation Period : 1/1/1932 - 31/12/1987

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Figure 2

APPENDIX B

CATCHMENT SUMMARY/
DEVELOPMENT FOR WATER SUPPLIES

APPENDIX B

CATCHMENT SUMMARY / DEVELOPMENT FOR WATER SUPPLIES

B1. CATCHMENT SUMMARY

B1.1 The Wyre catchment drains the eastern side of the Bowland Fells in Lancashire, and flows into Morecambe Bay. The major part of the catchment is agricultural, with pasture for sheep and cattle, with the upper reaches surrounded by moorland used mainly for shooting and rough grazing.

Extensive flood defence works have been carried out in the lower reaches of the river, including channel straightening, bank reformation work and construction of two flood basins.

The water quality is generally of a high standard, either Class 1A or 1B, although there are problems with high acidity in the upper reaches of the Wyre.

Between Abbeystead and Garstang the Wyre is used for conveying water abstracted from the River Lune as part of the LCUS. This water, as well as additional water from the Wyre itself, is abstracted at Garstang (when conditions permit).

The LCUS, Lancashire Conjunctive Use Scheme, comprises a number of diverse sources, both within and outside the Wyre catchment, shown on fig.B1, viz.:

Stocks Reservoir
Barnacre Reservoirs, with associated river intakes
River abstractions from R. Lune and transfer to R. Wyre
River abstraction from R. Wyre
Groundwater abstraction from the Fylde aquifer.

In addition to the LCUS groundwater abstractions from the central portion of the Fylde aquifer, there are further groundwater uses by industrial concerns to the north and the south and private individuals throughout.

There are additional surface water abstractions for public water supplies and canal use from various tributaries of the Wyre.

B1.2 The groundwater component of the LCUS is derived from the Permo-Triassic Sherwood Sandstones of the Fylde aquifer, bounded by older Carboniferous strata to the east, and overlain by low permeability Mercia Mudstones to the west.

The Carboniferous strata, forming the high ground on which the River Wyre rises, comprises predominantly mudstones and sandstones with some limestones. Faulting of the strata suggests that direct hydraulic continuity exists between the Carboniferous and the Permo-Triassic aquifer, and in the investigations in the early 1970's it was assumed that the majority of the recharge to the aquifer was derived from this source. However the presence of low permeability Manchester Marls at the base of the Permo-Triassic sequence is likely to limit such flow, particularly south of Garstang. In the west, high groundwater salinities are present, indicating no significant groundwater flow occurs westward under the mudstones.

The Fylde aquifer is mainly covered by drift deposits, comprising glacial silts, sands, gravels and boulder clay, the latter tending to limit rainfall infiltration. However the deposits are highly variable in composition and disposition. Furthermore there is known to be hydraulic continuity with stretches of various watercourses which cross the aquifer, either directly or via permeable alluvial deposits.

Groundwater movement is generally from the east to the northwest in the north and to the southwest in the southern part, with the groundwater divide occurring just south of Broughton.(fig.B2). Under natural (non-pumping) conditions, outflow to the various watercourses takes place along stretches where the glacial till is absent or has been incised (eg. Wyre, Calder, Brock, Cocker and Pilling Water).

Groundwater gradients are very shallow in the north west of the area, coinciding with the extensive tract of marine and estuarine alluvium. Piezometric heads are naturally above sea level, even at the coast.

B2. DEVELOPMENT FOR WATER SUPPLIES

B2.1 The earliest developments for public water supply were surface water abstractions from the Upper Wyre (Tarnbrook Wyre) using catchwaters and stream intakes. The intakes catch the whole flow of the various tributaries and a reservoir (Abbeystead) was built to supply compensation to mills on the River Wyre. These compensation rights were bought out in the 1920's, although a small flow is released from the reservoir in addition to a fish pass. Barnacre reservoirs were built in the late 1800's, with intakes similarly taking the whole flow of the River Calder and Grizedale Brook with no compensation or bypass at low/medium flows.

There is a further intake on the River Calder, which can take the whole flow, without compensation for the Lancaster canal.

Groundwater has been abstracted from the northern part of the Fylde aquifer since the 1890's, although the rest of the aquifer was virtually unexploited until investigations in the late 1950's by Fylde Water Board in the area between Garstang and Preston.

The interim report of the Northern Technical Working Party (1967) identified future shortages in Lancashire during the 1970's. In 1969 Lancashire River Authority proposed a scheme with conjunctive use of reservoirs, Ribble, Wyre and Lune. In 1971 Water Resources in the North Working Group II recommended a scheme which included an enlarged Stocks Reservoir, the Fylde aquifer, and abstractions from the rivers Lune and Wyre. This was developed (without enlarging Stocks reservoir) into the current LCUS.

B2.2 Investigations of the aquifer started in the late 1950's with trial boreholes to prove the existence of the aquifer and to determine its possible yield. The quantities available for supplies were limited by statute, later licences, and the table below indicates the development:-

Year	max.daily Ml/d	max. annual Ml.
1960	9	1932
1961	54.5	12424
1974	73	14356(subject to conditions)

B2.3 The principle of conjunctive use is that by operating the system as a single unit, greater yields and average supplies can be obtained than from the separate components.

In the LCUS, direct supplies (by gravity) from the reservoirs are the cheapest sources. The boreholes can be used to back up the reservoirs, particularly for short periods of intensive use. The river abstractions can be used to 'rest' the reservoirs early/late in the season as soon as they respond to rainfall. However it should be noted that in drought periods flows will be below the prescribed flow levels and additional yield for these sources is limited. Thus the licensed totals for the scheme give a misleading impression of water availability.

B2.4 The original concept for the groundwater component of the LCUS licence, which envisaged balanced use of the Fylde aquifer from north to south, has not been followed, due to the variations in pumping head and water quality. The operating strategy, within the existing licence conditions, optimises groundwater usage in terms of borehole efficiency (pumping costs) and quality (treatment costs).

As the LCUS evolved, the need to determine suitable operating policies and appropriate licences, especially for the groundwater sources, developed. Resource simulation work was undertaken and major test pumping of boreholes was carried out in the period 1972-74.

From 1981, work on the economic operation of the LCUS was carried out, to optimise the least cost operating policies with the requisite reliability.

NATIONAL RIVERS AUTHORITY - NORTH WEST REGION

[lcusappb] May 1994

Lancashire Conjunctive Use Scheme – General Features

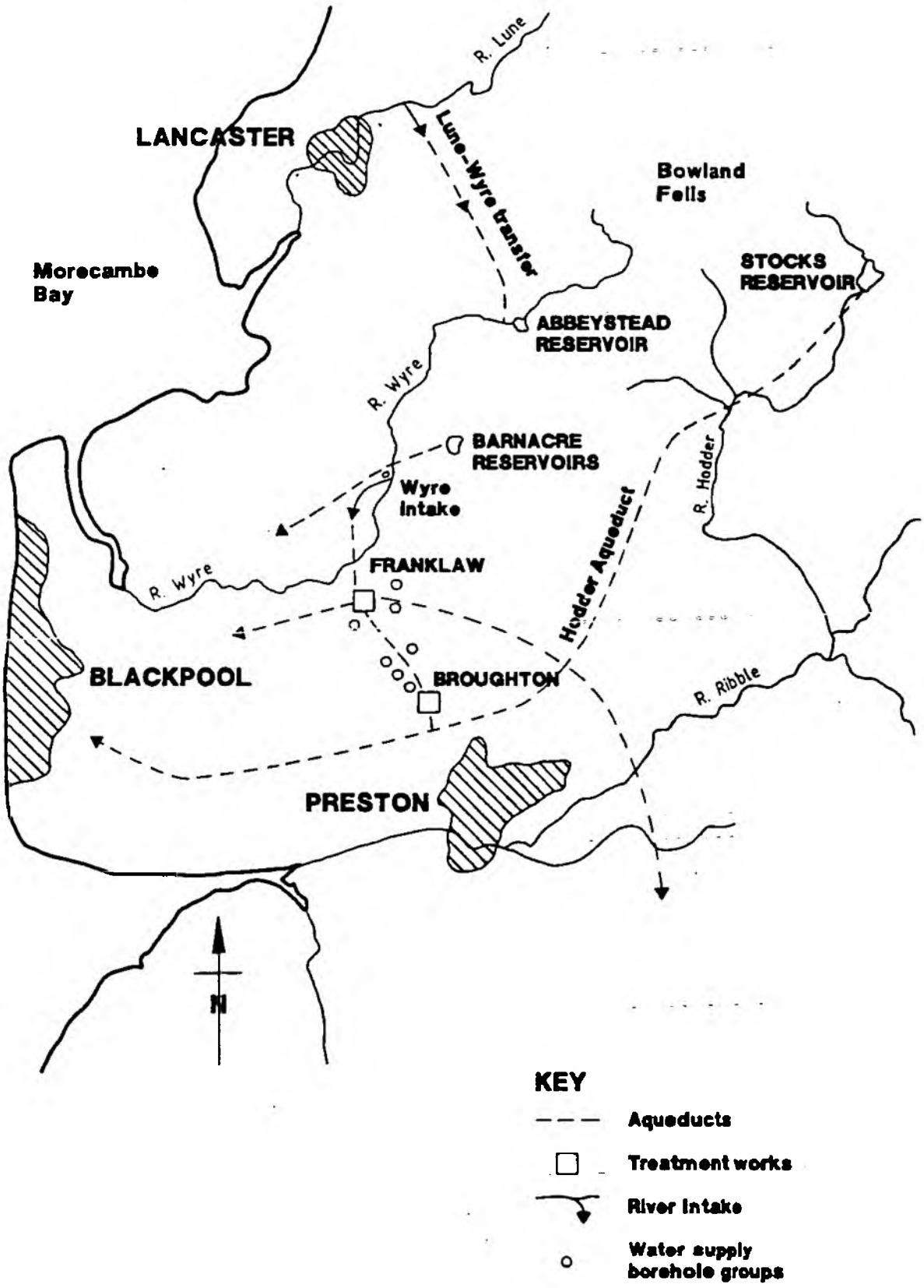
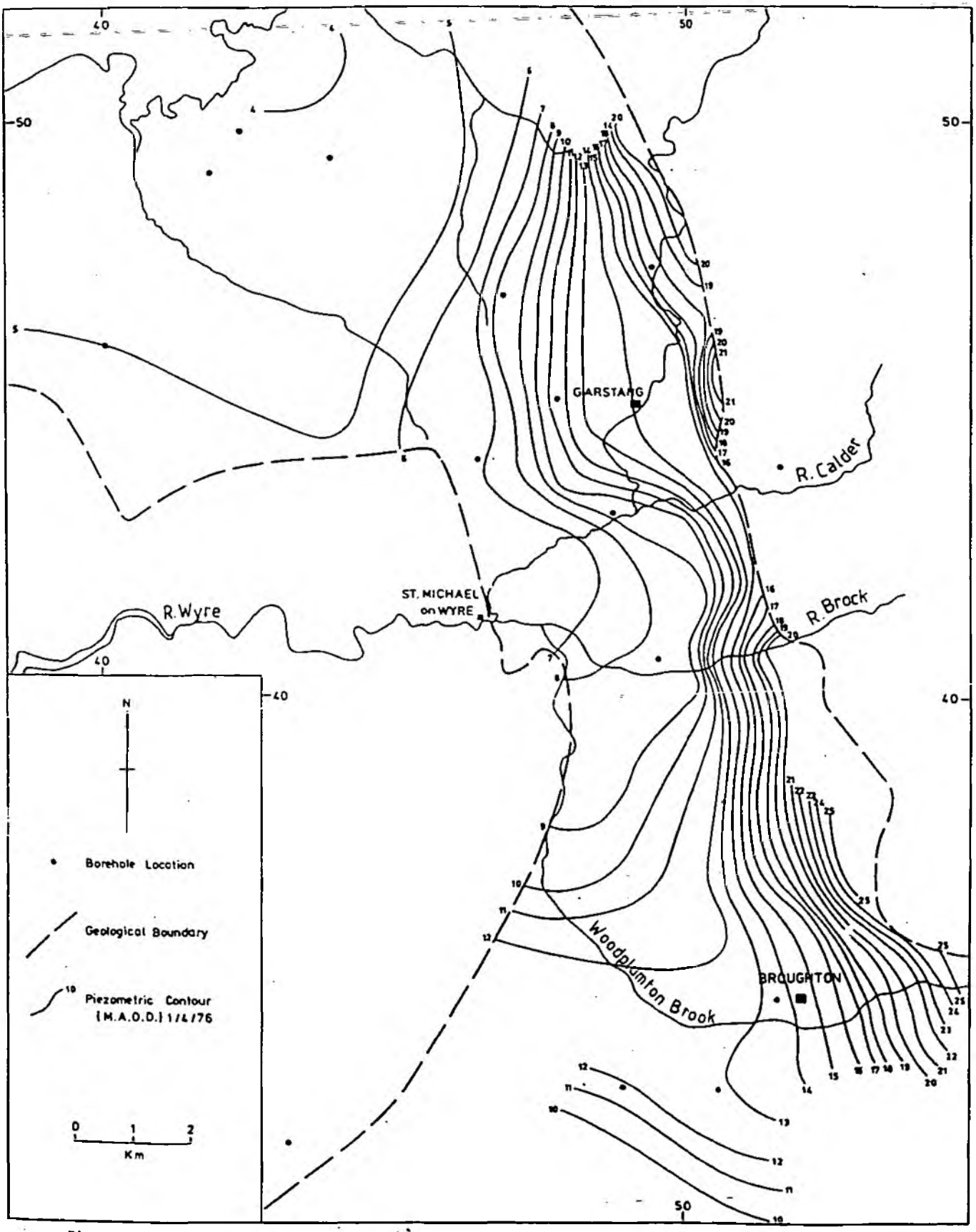


FIG B1



Piezometric map of the Triassic Sandstone aquifer. (After Sage & Loyd)

FIG B2

APPENDIX C

MODELLING AND LICENCE CONDITIONS

APPENDIX C

MODELLING AND LICENCE CONDITIONS

C1 MODELLING

C1.1 In 1971 Walsh reviewed available methods for simulation and analysis of water resource systems and concluded that simulation was the preferred approach to studying the operation of the LCUS. A simulation model, used to investigate a large number of operating policies, suggested the final order of preference for use of the various sources was:-

1. Barnacre reservoirs
2. Stocks reservoir
3. River Wyre abstraction, supported by River Lune transfer when necessary
4. Borehole abstractions
5. Further calls on Stocks, then the boreholes.

The philosophy of the LCUS simulation model was to utilise the groundwater resources of the Fylde to support river and upland reservoir sources in times of low flow/high demand, by developing available aquifer storage.

The resulting policy, applied in simulation of the historic period, showed that supplies could have been maintained through both 1933-34 and 1959 droughts.

C1.2 In 1981, North West Water Authority (NWWA) carried out an investigation of the economic operation of the LCUS, similar to an earlier study of the Lake District sources. Marginal costs (£/Ml) were derived for the different system configurations appropriate to each level of demand. The report envisaged the combination of LCUS and Lake District outputs to allow a least cost allocation of water on a regional basis in the Northern Command Zone (NCZ).

This was carried out, initially using in-house programs from NWWA's RP suite, and subsequently using MOSPA, which provided facilities for a more detailed simulation, and also advanced methods of optimisation to determine least-cost operating policies which maintained the desired reliability. Fig.C1 illustrates that the LCUS forms the southern part of the NCZ. The Fylde boreholes are represented by two groups, at Franklaw and Broughton. This has been found to be adequate for operating policy derivation and simulation, and allows incorporation of the overall licence limits of the system.

Simulation at an average daily NCZ demand of 900 Ml/d (ie at maximum system capacity) gives an average LCUS output for 1961-87 of 211.4 Ml/d, of which the two borehole groups comprise 17.8Ml/d. Actual borehole output for 1989 was 42Ml/d and the average for 1985-92 was 12.8 Ml/d. This is limited by economic constraints and the restriction of transfer capacity into distribution. If the capacity limits were removed, policies and marginal costs could be developed for abstractions increasing towards the licence limits. However this concentration on economics does not reflect environmental concerns.

C2. LICENCE CONDITIONS

C2.1 The LCUS groundwater licence conditions were derived from a groundwater model prepared by the Water Resources Board (WRB) (Oakes and Skinner, 1975). The model was developed from a series of pumping tests in 1972-74, carried out on groups of abstraction boreholes, with associated monitoring of groundwater levels and surface water flows, supplemented by historical groundwater data.

The principal source of recharge was assumed to be the Carboniferous strata to the east, because of the extensive clay drift cover, although it was recognised that hydraulic continuity existed in certain stretches of the rivers Wyre and Brock.

The criteria applied in determining the maximum acceptable abstractions from groundwater were:
i. Demand should not exceed available recharge (over a 3 year period), to ensure groundwater levels are not permanently depressed.
ii. Positive groundwater gradients should be maintained at aquifer boundaries (to prevent incursion of saline/poor quality groundwaters).
iii. The interest of existing abstractors should be assured.
(WRB, unpublished report, 1973).

The conditions applied to the licence attempted to encourage balanced use from north to south, and the abstraction limits were drawn so that, although intensive use may be made of the aquifer over short periods, the demands in the long term will not be such that the aquifer and drift water levels are permanently depressed.

Similarly, because there was concern over the level of recharge, the licence conditions included 3 year maximum total abstraction equivalent to 2 x the annual licence limit.

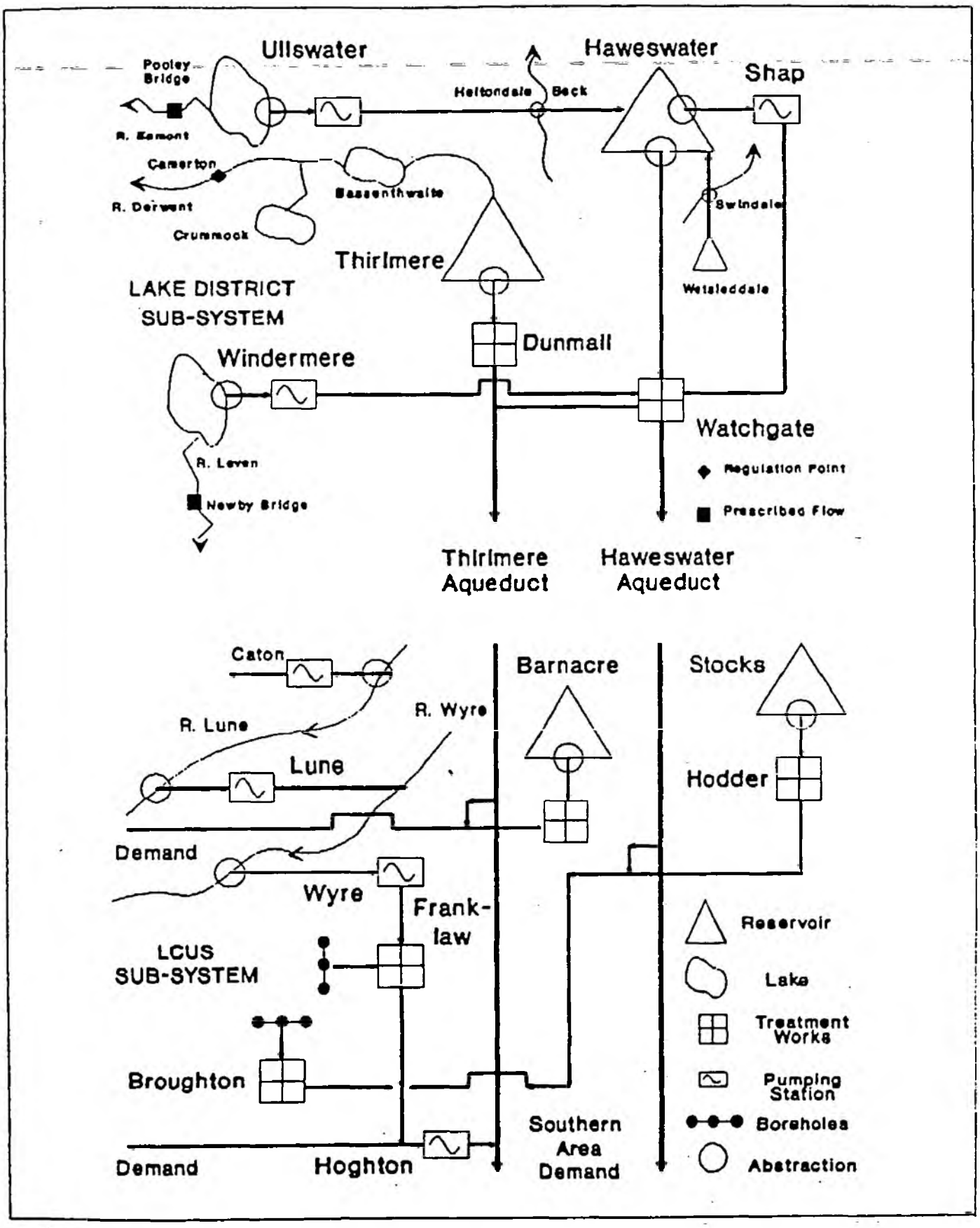
In formulating the LCUS licence it was recognised that ICI's existing abstraction, in the Pilling area, close to the coast, needed protection. There was also concern that the impact of additional abstraction further inland could result in reversal of groundwater gradients, and so induce saline intrusion from the coast and/or from beneath the Mercia Mudstones forming the western boundary of the aquifer. A conjunctive total was applied to the actual ICI and NWW abstraction from their northern borehole groups.

C2.2 The pumping carried out in 1972-74 identified groundwater levels in the drift and flows in certain watercourses were affected by abstraction from the main Sandstone aquifer. Reductions in head in the drift caused even by intermittent abstraction from the sandstone can result in delayed yield and drainage taking place after pumping has ceased. Threshold levels were set on two observation boreholes and two drift wells in the licence conditions.

This impact on surface waters was considered to some extent, and augmentation of various river stretches was also included in the licence conditions, subject to certain conditions. However it was not in terms of environmental issues such as conservation of groundwater dependent features. It is felt that the augmentation needs were not adequately addressed in this respect.

C2.3 Subsequent work, mainly related to the quality of water, inferred that "indirect recharge occurs through the present river alluvium into the glacial sands and is then transmitted significant distances ... through the sand/sandstone aquifer". It was concluded that this recharge mechanism was of "comparable importance to recharge or groundwater flows entering the sandstones across the eastern boundary from the Carboniferous aquifers" (Sage and Lloyd, 1978). The report also reinforced the complexity of the drift influence on ground/surface water interrelationships. (fig.C2)

The recently published 1:50,000 solid and drift geological maps of the Garstang area have also revised the interpretation of the Fylde aquifer in terms of its structure, boundary conditions and drift cover, such that the WRB model assumptions may now prove to be inappropriate.



Schematic of the Northern Command Zone System **FIG C1**

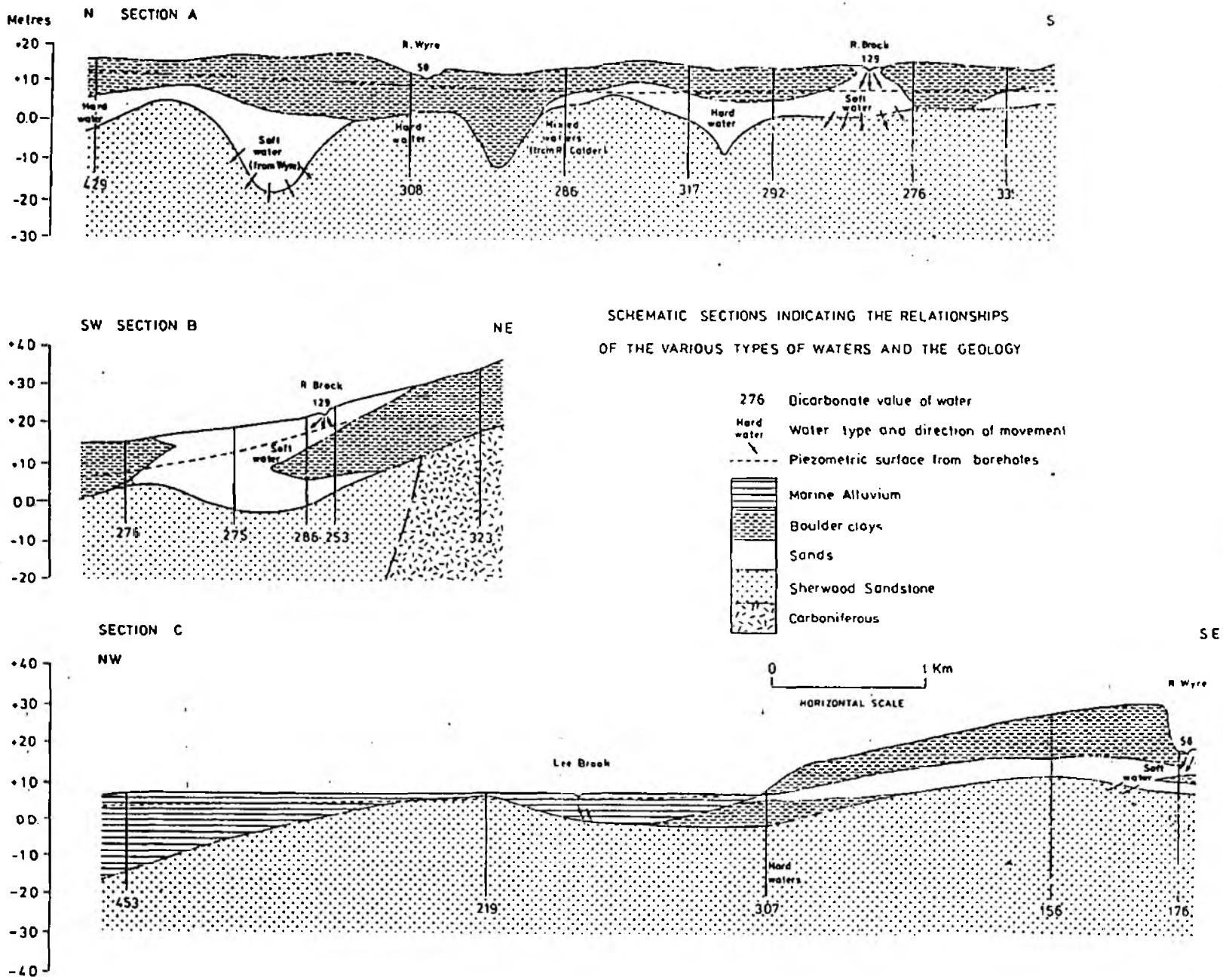


FIG C2

Hydrogeological cross-sections depicting recharge and flow mechanisms related to hydrochemistry.

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