COMPARATIVE ENVIRONMENTAL APPRAISAL OF STRATEGIC OPTIONS

Supplementary Report No 8

Volume 2 - Appendices

January 1994

Howard Humphreys *Consulting Engineers*

in Association with Cobham Resource Consultants

NATIONAL RIVERS AUTHORITY

NATIONAL WATER RESOURCES STRATEGY:

COMPARATIVE ENVIRONMENTAL APPRAISAL OF STRATEGIC OPTIONS

Volume 2: Appendices

Ref. 84.247.0/AW/3122/NRAEAAPP.R02

Howard Humphreys & Partners Ltd
Thorncroft Manor
Dorking Road
Leatherhead
Surrey KT22 8JB

January 1994

Brown & Root *Civil*

NATIONAL RIVERS AUTHORITY

NATIONAL WATER RESOURCES STRATEGY

COMPARATIVE ENVIRONMENTAL APPRAISAL OF STRATEGIC OPTIONS

FINAL REPORT

VOLUME 2 - APPENDICES

CONTENTS

APPENDICES CONTENTS (Cont.)

NATIONAL RIVERS AUTHORITY

NATIONAL WATER RESOURCES STRATEGY

COMPARATIVE ENVIRONMENTAL APPRAISAL OF STRATEGIC OPTIONS

FINAL REPORT

VOLUME 1 - MAIN REPORT

CONTENTS

TABLES

FIGURES

APPENDIX A

Terms of Reference

NATIONAL RIVERS AUTHORITY

TENDER FOR ENVIRONMENTAL ASSESSMENT CONSULTANCY

CONTENT

- Instructions to Tenderers
- Terms of Reference (including Pricing Schedule)
- Conditions of Contract
- Form of Tender

February 1993

INSTRUCTIONS TO TENDERERS

1.1 THE TENDER DOCUMENTS AND ACKNOWLEDGEMENT OF RECEIPT

Companies invited to Tender shall have received two sets of documents listed in the covering letter. Following receipt of the Tender documents the Tenderer shall promptly acknowledge receipt of the documents in writing indicating whether or not it is intended to submit a Tender.

1.2 AMENDMENTS

Prior to the final date for submission of tenders the Authority may issue amendments to clarify, modify or add to the Tender documents. A copy of each amendment will be issued to each Tenderer and shall become part of the Tender documents; receipt thereof shall be acknowledge in writing by return.

1.3 PREPARATION OF TENDER

The Tenderer shall be responsible for obtaining all information necessary to submit a Tender. A request for clarification relating to information contained within the tender documents should be made to the Purchasing Officer, in writing, not less than four working days before the closing date for receipt of Tenders. If any doubt should remain, the Tenderer shall when tendering, set forth the same in a separate Schedule marked "Additional Information".

1.4 SUGGESTIONS FOR MODIFICATION TO TERMS OF REFERENCE

If the Tenderer considers that he can offer any advantage by any modification to the Terms of Reference such suggested modifications should be detailed in a separate schedule. However, such an offer will only be considered if it accompanies a bona fide tender which accords with condition 1.6 below and itself constitutes a fully priced alternative tender.

1.5 RESERVATIONS OR QUALIFICATIONS

Any Tender which incorporates reservations or qualifications may be regarded as invalid unless it is considered by the Authority that the reservations or qualifications are warranted by special circumstances.

1.6 SUBMISSION OF TENDER

The Tender must be submitted on the documents provided which must not be detached from the associated documents. The Authority will not take into consideration any Tender, unless the Tender has been legibly and fully completed in ink. Except for completing the spaces specifically provided in the tender documents the tenderer shall not deface nor make any alteration in the documents annexed hereto.

1.7 COSTS OF TENDERS

The Authority will not be responsible for or pay for any expenses or costs incurred in the preparation of or submission of the tender.

1.8 CLOSING DATE FOR RECEIPT OF TENDERS

One copy of the Tender documents with the Form of Tender duly completed must be enclosed and sealed in an envelope which must carry the pre-addressed tender label provided. No other means of identification is permissable. **It must be delivered to the offices of the Authority not later than midday on 10 March 1993** at Rivers House, Waterside Drive, Aztec West, Almondsbury, Bristol BS12 4UD.

1.9 ACCEPTANCE OF TENDERS

Tenders should be valid for at least 30 days from the latest date for receipt. The period of Tender validity should be explicitly stated and an indication given of any likely changes to Tender conditions after expiry of this period.

The Authority does not bind itself to accept the lowest or any Tender and reserves the right to accept all or part of a Tender. It shall be a condition of any Contract arising as a result of any Tender that the Authority is not bound to purchase all or any of the services from the successful Tenderer and shall have the right in its absolute discretion to purchase all or any of the services from another source.

NATIONAL RIVERS AUTHORITY

ENVIRONMENTAL ASSESSMENT CONSULTANCY

TERMS OF REFERENCE

1. INTRODUCTION

The National Rivers Authority (NRA) is committed to publishing a water resources strategy for England and Wales to meet demands up to the year 2021. This strategy is likely to have several components, including elements of demand management, local source development and inter-regional transfer.

A number of studies are already underway which address a variety of resource development and water transfer schemes, in terms of practicability, cost and environmental impact (see Table 1). These studies are being undertaken by several different agents, and are all due to be completed by about May 1993. Their findings will then need to be drawn together on a common footing, as input to the development of an integrated national water resources strategy. This will be done by the Project Management Team of NRA Headquarters staff assisted by Sir William Halcrow and Partners (Halcrow), with input from others on discrete tasks where appropriate.

One such discrete task is the development of a framework that will enable objective comparison of positive and negative environmental impacts of potential strategic water resource schemes.

A consultancy contract is now sought that will:

- set in context the likely impacts of the various options, through consideration of operations experience of existing schemes with similar components, published literature and relevant research;

- review scheme-specific environmental studies now in hand by others, as the relevant documents become available (see Table 1);

- make use of "without scheme" and "with scheme" river flow data (to be prepared by Halcrow), and related water quality and biotic information in order to assess aquatic impacts of potential schemes;

- develop a framework for comparison of environmental impacts of potential resource schemes.

The work will be carried forward as a desk study, although some site reconnaissance may be permitted, subject to:

- visit-specific consent from the Project Management Team;
- constraints of public access;
- rigorous observance of the need for discretion and for scheme proposals to be kept confidential.

Consultation is not required with parties other than national and regions office of the NRA or, through the NRA, with consultants actively engaged on studies listed in Table 1. NRA functions which would need to be consulted include fisheries, recreation, conservation, navigation and water quality.

2. SCOPE OF WORK

2.1 General

This study is essentially a strategic review of all relevant environmental data on resource development schemes generally and on the options shown in Table 1 particularly. Principal tasks are to:

(i) investigate impacts of existing schemes with similar components, including inter-catchment transfers and significant river regulation schemes;

(ii) review published literature on the design, operation and associated environmental impacts of such schemes, and other relevant information including past and present work on residual flows to estuaries;

(iii) review the implications of proposed EC Regulation on environmental assessment for strategic planning, and of the DoE publication "Policy Appraisal and the Environment" (HMSO, 1991);

(iv) collate the environmental assessments carried out by others for the options listed in Table 1 identify any deficiencies in them, and make outline recommendations regarding the work needed to rectify such deficiencies;

(v) assimilate results of hydrological modelling carried out in relation to specific schemes, taking particular note of frequency of operation;

(vi) develop and apply a framework for objective comparison of the environmental implications of each option;

(vii) prepare progress, interim and final reports on the above work, and maintain general liaison with the Project Management Team.

By reference to any published data that exist, and to reports and other information thatTasks (i) and (ii) shall be conducted in light of the NRA national and regional water resource strategies, considering the implications of the schemes shall be assessed in early terms as whilst outputs from current work by others are awaited. The work should reflect international as well as national experience and research.

- impacts foreseen prior to construction, and the design and operations

Task (iv) shall be conducted to accommodate the reports become available, and shall take the results of Tasks (i) and (ii) into account.

- impacts experienced during the operational phase, the extent to which

Task (v) shall build upon the earlier tasks to address the environmental impacts on aquatic and terrestrial ecosystems of the flow regime changes implicit in the hydrographs.

- changes to scheme operating rules since original commissioning, the

Task (vi) with provision for a report to form the environmental implications of alternative resource development strategies appropriate to the future water needs of England and Wales. Operating rule changes are likely to include measures motivated by environmental as well as by economic considerations. The effectiveness of the former in achieving

2.2 their Impacts of Existing Schemes should be assessed in such cases.

The review of existing schemes shall particularly include an assessment of operational experience of the following issues: to river water transfer projects, river regulation and groundwater augmentation can be greatly assisted through utilising information relating to existing schemes with similar elements.

- effects on fisheries and fish migration;

At present there are four major river to river transfer schemes in operation in the UK, diurnal modulation of operating rules;

- creation of artificial freshets;

(i) • Ely Ouse to Essex transfer between catchments of fish diseases and parasites;
(ii) • Exe transfer between catchments of other biota including algae,
(iii) Lune invertebrates and fish;
(iv) • Trent effects on water chemistry and water quality;
(v) • Tyne sedimentation.

- flooding;

There are also recreation, navigation and amenity source schemes in UK which are likely to have some of the same implications for the environment as the options shown in Table 1. Reservoirs such as Roadford and Wimbleball in the South West, Clywedog

2.3 Literature Review Kielder in Northumbria are all used to regulate downstream river abstractions. Existing groundwater augmentation schemes include the Shropshire The literature review is intended to Groundwater Scheme in the NRA Midlands as possible The knowledge upon Southern Region strategic environmental study is based. The review should embrace published research results and reports on the following and any other relevant areas of enquiry:

Tasks (i) and (ii) above can be carried out largely independently of inputs by others. These tasks will form the groundwork of the study, to be carried out in the early weeks whilst outputs from current work by others are awaited. The work should reflect international as well as national experience and research.

Task (iv) shall be undertaken as the scheme reports become available, and shall take the results of Tasks (i) and (ii) into account.

Task (v) shall build upon earlier work, to develop objective assessments of aquatic and terrestrial impacts associated with the flow regime changes implicit in the hydrographs.

Task (vi) will provide a main output from the study, for use in comparing alternative resource development strategies appropriate to the future water needs of England and Wales.

2.2 Impacts of Existing Schemes

The development of an environmental assessment for strategic resource development options such as large scale river to river water transfer projects, river regulation and groundwater augmentation can be greatly assisted through utilising information relating to existing schemes with similar elements.

At present there are five major river to river catchment transfer schemes in operation in the UK, namely:

(i) Ely Ouse - Essex Rivers
(ii) Exe - Taw
(iii) Lune - Wyre
(iv) Trent - Witham - Ancholme
(v) Tyne - Wear - Tees.

There are also a number of other water resource schemes in UK which are likely to have some of the same implications for the environment as the options shown in Table 1. Reservoirs such as Roadford and Wimbleball in the South West, Clywedog in Wales and Kielder in Northumbria are all used to regulate downstream river abstractions. Existing groundwater augmentation schemes include the Shropshire Groundwater Scheme in Severn Trent NRA region and the Test Augmentation Scheme in Southern region.

- extent to which schemes with components similar to options listed in Table 1 are

  - planned
  - practised

  in UK, Europe and worldwide;

- design and operation of such schemes;

- operational experience of such schemes, with particular reference to environmental impact;

- details of any relevant research;

- extent, design and operation, and environment-related experience from similar schemes in the UK;

- studies of flow and quality related issues which could be relevant, including for example ecologically acceptable low flows and migratory fish movements.

The literature review shall include consideration of relevant documents on, for example, major catchment transfer and river regulation schemes that have been investigated in the past, but not yet implemented.

Where research or field studies into impacts of similar schemes have been carried out, details of procedures followed, key findings and conclusions shall be ascertained.

Studies of migratory fish movements and/or fisheries management have been carried out on a number of rivers, including several in North West Region, the Welsh Dee, Towy, Taw/Torridge, Fowey, Tamar/Tavy, Exe, Hampshire Avon, Test, Itchen and Thames. This and other similar work should be reviewed as appropriate.

Particular attention should be focused on research/study findings in relation to issues highlighted at the end of Section 2.2 above.

The literature review shall also include task (iii) identified in Section 2.1. Implications of the proposed EC legislation on strategic planning EA and DoE guidelines shall be noted in the Interim Report and, where appropriate, shall be taken into account in the remaining activities of the study described below.

2.4 Collation of Environmental Assessments

Environmental Assessments now in preparation for potential resource options shall be collated in order to:

- summarise them on a consistent basis;
- provide scheme-specific input to the strategic environmental review.

The level of investigation, current status and timing of outputs from the various option studies are shown in Table 1.

All reports pertaining to the investigations will be provided as they become available. The investigations are to be based on existing data.

In each case, environmental assessment work contained in the various reports shall be reviewed to ascertain:

- whether all areas of potential impact have been identified;
- the rigour with which assessments have been made for each identified area of impact;
- areas of deficiency or weakness in the assessments.

Where areas of deficiency are noted, recommendations shall be put forward as to how they may be overcome.

2.5 Assimilation of Hydrological Modelling Results

Within the overall National Resources Strategy, hydrological data relating to the preferred options will be generated. This phase of work is due to be undertaken during April, May and June 1993. Based upon the hydrological data available, an assessment is to be made of the impacts of the various options on the whole riverine environment. The key issues to be addressed here are:

- flow regime;
- channel morphology;
- water quality;
- aquatic and river corridor ecology;
- conservation;
- fisheries;
- navigation and recreation;
- agriculture and land drainage.

The assessment shall build upon any relevant work contained in the environmental studies now in hand as part of the investigations of the four schemes referred to in Section 2.1.

The appropriateness of alternative operating regimes (including, for example, spate sparing and diurnal flow variation) for impact mitigation for a range of resource management situations shall also be addressed.

The assimilation shall be conducted at a strategic level using evidence from the literature survey, study reports and hydrological modelling output.

2.6 Strategic Framework

In order to aid both the strategic assessments of resources development options, and to indicate issues requiring further investigation, a framework for comparing the various options and the level of environmental assessments undertaken shall be formulated. In developing the framework, consideration shall be given to both the construction and operational phases of schemes and all their various components. Environmental impacts associated with at least the following areas of interest shall be addressed:

- flow and level;
- water quality;
- channel morphology;
- ecology;
- conservation;
- fisheries and angling;
- navigation;
- recreation;
- agriculture/land use;
- landscape/visual impact;
- archaeology and heritage;
- noise;
- dust;
- traffic.

The framework shall identify where appropriate, operational measures that can be deployed to mitigate adverse environmental impacts. It should also identify not only adverse impacts but also positive benefits. Consideration shall be given to applying a subjective scoring or weighting system to aid comparison of alternatives. In addition an indication of the degree of uncertainty of the environmental impact should be provided.

Design of the framework is a key function of the study, and some Client consultation in initial drafts will be necessary.

2.7 Reporting

The following reports will be required in the course of the study:

- progress reports;
- interim report;
- final report.

Progress reports shall be submitted monthly. They shall comprise a two page summary of progress over the period, work planned for the following period and achievement against programme and budget.

The interim report shall be submitted in mid July 1993. It will include:

- summary review of existing schemes identified, and associated impacts;
- literature review findings;
- a summary review of the environmental assessments for the proposed schemes insofar as these are available;
- an overview of the methodology proposed for preparing the framework for the strategic environmental assessment;
- details of any difficulties encountered on the study so far.

The final report must be submitted in draft form initially, and shall occupy one or more volumes as appropriate. A draft contents list shall be submitted one month before the draft report is due, to indicate its proposed structure and to allow modifications to be made if appropriate.

The final report shall include at least the following:

- overview of work carried out and approach adopted;
- assessment of impacts of existing schemes;
- literature review findings;
- identification of key issues;
- review of schemes proposed;
- a detailed framework for comparing options;
- assessment of schemes based upon the hydrological modelling results;

- requirements for further environmental assessment work.

20 copies of all progress reports, interim report and draft report and 20 copies of all final reports will be required, plus an additional unbound copy of the final report.

2.8 Programme

The successful tenderer will prepare a programme for the study in consultation with the NRA. Key dates already identified are as follows:

- commencement: 8 April 1993;
- interim report: 16 July 1993;
- draft final report: 24 September 1993;
- amended final report: 29 October 1993.

In addition, a presentation to NRA consultees will be required, after production of the Draft Final Report, at the end of September 1993.

3. STAFFING REQUIREMENTS

The project team shall include as a minimum the following specialists, together with executive direction and technical support as appropriate to fulfil the Terms of Reference within the specified timescale:

POST	MINIMUM PREFERRED EXPERIENCE	MINIMUM INPUT (man-days)
Project Manager	15 years involvement in project management/coordination, particularly of environmental assessments and water resource development studies.	55
Water Quality Scientist	15 years involvement in water quality determination and management and the assessment of the water quality implications of resource development schemes.	25
Fisheries Scientist	15 years experience in fisheries ecology and study of the impact of water resource developments on fisheries.	25

POST	MINIMUM PREFERRED EXPERIENCE	MINIMUM INPUT (man-days)
Aquatic Ecologist	10 years experience in aquatic ecology and the ecological assessment of changes in flow regime on the aquatic environment.	15
Hydrologist	10 years experience in the hydrological assessment of development projects, specifically water resources schemes.	15
Geomorphologist	10 years experience in assessing the impact of changes in river flow regimes on river morphology/sedimentation etc.	10
Recreation Specialist	10 years involvement in assessing the recreational impacts of development projects, specifically in relation to river, and river corridor recreational activities.	10
Other Specialists	10 years experience. As deemed appropriate by tenderers.	20

4. TENDERING INSTRUCTIONS AND CONTRACT DETAILS

4.1 Tenderers must complete the following Pricing Schedule - exclusive of V.A.T.:

	Rate per Day	No. days	Sub-total (£)	Total (£)
Project Manager		55		-
Water Quality Scientist		25		-
Fisheries Scientist		25		-
Aquatic Ecologist		15		-
Hydrologist		15		-
Geomorphologist		10		-
Recreation Specialist		10		-
Other Specialists - Tenderers to specify:				-
Total Fees			-	
Travel & Subsistence Printing & Documents Wordprocessing Other (as specified)			- - - -	
Total Tendered Sum				£________

4.2 Rates for additional work, if any, will be by negotiation with the consultant appointed.

4.3 The successful tenderer may re-allocate human and financial resources within the overall tendered sum by agreement with the National Rivers Authority.

4.4 The Tender must also be accompanied by the following information:

(i) a summary of the consultant's understanding of the brief and skills required;

(ii) staffing proposals with C.V.'s of key staff;

(iii) an indication of how the consultant would manage the various elements of the work together with key accountabilities;

(iv) assumptions used in arriving at the tender price for travel and subsistence;

4.5 It should be assumed that reports will be required to a standard achievable from standard wordprocessors in black and white.

4.6 Following the selection of the successful consultant, the NRA may wish to amend the Terms of Reference in the light of new information and then negotiate a contract with the successful consultants.

4.7 Instructions to tenderers are attached.

4.8 The study shall be carried out in accordance with the NRA's standard General Conditions of Contract for the Supply of Goods/Services, copy attached.

Table 1

OPTION STUDIES

OPTION	REGIONAL RESPONSIBILITY	STUDY RESPONSIBILITY	LEVEL OF INVESTIGATION	CURRENT STATUS	REPORTS
a) Major Transfer Options					
• Trent to Anglian	Anglian	Atkins	Engineering/ environmental feasibility studies	Complete	Final report available
• Severn to Thames	Thames	Atkins		Commenced Oct 92	Interim early Jan 93 Final mid April 93
• Severn to Trent	Severn Trent	Atkins		Commenced Dec 92	Draft Final early April 93 Final early May 93
• BWB Canal Transfer	Head Office	BWB/Binnie		Commenced Nov 92	Final mid May 93
b) Other Options					
• Vale of York Groundwater	Yorkshire	Halcrow	Environmental statement	Commenced Dec 92	Final mid February 93
• Birmingham Rising Groundwater	Severn Trent	TBA	Outline assessment only of engineering and environmental implications	Due to commence April 93	Final end May 93
• Vyrnwy Redeployment	Severn Trent / North West	ST/NW/Binnie		Commenced Nov 92	Papers consistent with level of investigation will be available for all this group of studies by April 1993
• Kielder	Head Office / Northumbria	Halcrow			
• Craig Goch	Head Office / Welsh	Halcrow			
• Barrages (Wash/Dee)	Head Office	Halcrow			
• National Water Grid	Head Office	Halcrow			
• Effluent Reuse	Head Office	Halcrow			
• Artificial Recharge	Head Office	Halcrow			
• Tankers/Water Sacs	Head Office	Halcrow			
• Undersea Pipelines	Head Office	Halcrow			
• Desalination	Head Office	Halcrow			

Table 1
OPTION STUDIES

OPTION	REGIONAL RESPONSIBILITY	STUDY RESPONSIBILITY	LEVEL OF INVESTIGATION	CURRENT STATUS	REPORTS
a) Major Transfer Options					
• Trent to Anglian	Anglian	Atkins	Engineering/ environmental feasibility studies	Complete	Final report available
• Severn to Thames	Thames	Atkins		Commenced Oct 92	Interim early Jan 93 Final mid April 93
• Severn to Trent	Severn Trent	Atkins		Commenced Dec 92	Draft Final early April 93 Final early May 93
• BWB Canal Transfer	Head Office	BWB/Binnie		Commenced Nov 92	Final mid May 93
b) Other Options					
• Vale of York Groundwater	Yorkshire	Halcrow	Environmental statement	Commenced Dec 92	Final mid February 93
• Birmingham Rising Groundwater	Severn Trent	TBA	Outline assessment only of engineering and environmental implications	Due to commence April 93	Final end May 93
• Vyrnwy Redeployment	Severn Trent / North West	ST/NW/Binnie		Commenced Nov 92	Papers consistent with level of investigation will be available for all this group of studies by April 1993
• Kielder	Head Office / Northumbria	Halcrow			
• Craig Goch	Head Office / Welsh	Halcrow			
• Barrages (Wash/Dee)	Head Office	Halcrow			
• National Water Grid	Head Office	Halcrow			
• Effluent Reuse	Head Office	Halcrow			
• Artificial Recharge	Head Office	Halcrow			
• Tankers/Water Sacs	Head Office	Halcrow			
• Undersea Pipelines	Head Office	Halcrow			
• Desalination	Head Office	Halcrow			

CONDITIONS OF CONTRACT FOR THE PROVISION OF CONSULTANCY SERVICES

NRA

These Conditions may only be varied with the written agreement of the Client. No terms or conditions put forward at any time by the Consultant shall form any part of the Contract.

1. Definitions

In these conditions:

- 'Client' means the National Rivers Authority;
- 'Consultant' means the person, firm or company to whom the Contract is issued;
- 'Project' means the services to be provided as specified in the Tender;
- 'Premises' means the location where the Project is to be performed, as specified in the Tender;
- 'Contract' means the contract between the Client and the Consultant consisting of the Purchase Order, these Conditions and any other documents (or parts thereof) specified in the Purchase Order;
- 'Purchase Order' means the document setting out the Client's requirements for the Contract.

2. The Project

2.1 The Consultant shall complete the Project with reasonable skill, care and diligence in accordance with the Contract.

2.2 The Consultant shall provide the Client with such reports of his work on the Project at such intervals and in such form as the Client may from time to time require.

2.3 The Client reserves the right by notice to the Consultant to modify his requirements in relation to the Project and any alteration to the Contract fee or the completion date arising by reason of such modification shall be agreed between the parties. Failing agreement the matter shall be determined by arbitration in accordance with the provisions of Condition 15.

3. Fees and Expenses

3.1 The Client shall pay to the Consultant fees at the rate specified in the Purchase Order.

3.2 The Consultant shall be entitled to be reimbursed by the Client the amount of all expenses reasonably and properly incurred by him in the performance of his duties hereunder subject to production of such evidence thereof as the Client may reasonably require.

3.3 Unless otherwise stated in the Contract, payment will be made within 30 days of receipt and agreement of invoices, submitted monthly in arrears, for work completed to the satisfaction of the Client.

3.4 Value Added Tax, where applicable, shall be shown separately on all invoices as a strictly net extra charge.

4. Audit

The Consultant shall keep and maintain, until two years after the Contract has been completed, records to the satisfaction of the Client of all expenditures which are reimburseable by the Client and of the hours worked and costs incurred by the Consultant or any employees of the Consultant. The Consultant shall on request afford the Client or his representatives such access to those records as may be required by the Client in connection with the Contract.

5. Corrupt Gifts or Payments

The Consultant shall not offer or give, or agree to give, to any member, employee or representative of the Client any gift or consideration of any kind as an inducement or reward for doing or refraining from doing, or for having done or refrained from having done, any act in relation to the obtaining or execution of this or any other contract with the Client or for showing or refraining from showing favour or disfavour to any person in relation to this or any such contract. The attention of the Consultant is drawn to the criminal offences created by the Prevention of Corruption Acts 1889 to 1916.

6. Copyright

6.1 All reports and other documents and materials and the copyright or similar protection therein arising out of the performance by the Consultant of his duties hereunder are hereby assigned to and shall vest in the Crown absolutely.

6.2 The provisions of this Condition 7 shall apply during the continuance of this Contract and after its termination howsoever arising.

7. Indemnities and Insurance

7.1 The Consultant shall indemnify and keep indemnified the Client, the Crown, its servants and agents against all actions, claims, demands, costs and expenses incurred by or made against the Client or the Crown, its servants or agents in respect of any loss or damage or personal injury (including death) which arises from any advice given or anything done or omitted to be done under this Contract to the extent that such loss, damage or injury is caused by the negligence or other wrongful act of the Consultant, his servants or agents.

7.2 The Consultant (if an individual) represents that he is regarded by both the Inland Revenue and the Department of Social Security as self-employed and accordingly shall indemnify the Client against any tax, national insurance contributions or similar impost for which the Client may be liable in respect of the Consultant by reason of this Contract.

7.3 The Consultant shall effect with an insurance company or companies acceptable to the Client a policy or policies of insurance covering all the matters which are the subject of the indemnities and undertakings on the part of the Consultant contained in this Contract in the sum of £500,000 at least in respect of any one incident and unlimited in total, unless otherwise agreed by the Client in writing.

7.4 If requested, a certificate evidencing the existence of such policies shall be provided by the Consultant to the Client.

8. Racial Discrimination

The Consultant shall not unlawful discriminate within the meaning and scope of the provisions of the Race Relations Act 1976 or any statutory modification or re-enactment thereof relating to discrimination in employment. The Consultant shall take all reasonable steps to ensure the observance of these provisions by all servants, employees or agents of the Consultant and all sub-contractors employed in the execution of the Contract.

9. Official Secrets Acts and Confidentiality

9.1 The Consultant undertakes to abide and procure that his employees abide by the provisions of the Official Secrets Acts 1911 to 1989.

9.2 The Consultant shall keep secret and not disclose and shall procure that his employees keep secret and do not disclose any information of a confidential nature obtained by him by reason of this Contract except information which is in the public domain otherwise than by reason of a breach of this provision.

9.3 The provisions of this Condition 9 shall apply during the continuance of this Contract and after its termination howsoever arising.

10. Termination

10.1 The Consultant shall notify the Client in writing immediately upon the occurrence of any of the following events:

(a) where the Consultant is an individual and if a petition is presented for the Consultant's bankruptcy or a criminal bankruptcy order is made against the Consultant, or he makes any composition or arrangement with or for the benefit of creditors, or makes any conveyance or assignment for the benefit of creditors, or if an administrator is appointed to manage his affairs; or

(b) where the Consultant is not an individual but is a firm; or a number of persons acting together in any capacity, if any event in (a) or (c) of this Condition occurs in respect of any partner in the firm or any of those persons or a petition is presented for the Consultant to be wound up as an unregistered company; or

(c) where the Consultant is a company, if the company passes a resolution for winding-up or the court makes an administration order or a winding-up order, or the company makes a composition or arrangement with its creditors, or an administrative receiver, receiver or manager is appointed by a creditor or by the court, or possession is taken of any of its property under the terms of a floating charge.

10.2 On the occurrence of any of the events described in paragraph 10.1, or if the Consultant shall have committed a material breach of this Contract and (if such breach is capable of remedy) shall have failed to remedy such breach within thirty days of being required by the Client in writing to do so, or, where the Consultant is an individual, if he shall die or be adjudged incapable of managing his affairs within the meaning of Part VII of the Mental Health Act 1983 the Client shall be entitled to terminate this Contract by notice to the Consultant with immediate effect.

10.3 In addition to his rights of termination under paragraph 10.2, the Client shall be entitled to terminate this Contract by giving to the Consultant not less than thirty days' notice to that effect.

10.4 Termination under paragraphs 10.2 or 10.3 shall not prejudice or affect any right of action or remedy which shall have accrued or shall thereupon accrue to the Client and shall not affect the continued operation of Conditions 6 and 9.

11. Recovery and Sums Due

Wherever under this Contract any sum of money is recoverable from or payable by the Consultant, that sum may be deducted from any sum then due, or which at any later time may become due, to the Consultant under this Contract or under any other agreement or contract with the Client or with any department, agency or authority of the Crown.

12. Assignment and Sub-Contracting

12.1 The Consultant shall not assign or sub-contract any portion of the Contract without the prior written consent of the Client. Sub-contracting any part of the Contract shall not relieve the Consultant of any obligation or duty attributable to him under the Contract of these conditions.

12.2 Where the Client has consented to the placing of sub-contracts, copies of each sub-contract shall be sent by the Consultant to the Client immediately it is issued.

13. Notices

Any notice given under or by post or by registered post or by the recorded delivery service or transmitted by telex, telemessage, facsimile transmission or other means of telecommunication resulting in the receipt of a written communication in permanent form and if so sent or transmitted to the address to the address of the party shown on the Purchase Order, or to such other address as the party may by notice to the other have substituted therefore, shall be deemed effectively given on the day when in the ordinary course of the means of transmission it would first be received by the addressee in normal business hours.

14. Status of Contract

Nothing in the Contract shall have the effect of making the Consultant the servant of the Client or the Crown.

15. Arbitration

All disputes, differences or questions between the parties to the Contract with respect to any matter or thing arising out of or relating to the Contract, other than a matter or thing as to which the decision of the Client is under the Contract to be final and conclusive, and except to the extent to which special provision for arbitration is made elsewhere in the Contract shall be referred to the arbitration of two persons one to be appointed by the Client and one by the Consultant or their Umpire, in accordance with the provisions of the Arbitration Act 1950 or any statutory modification or re-enactment thereof.

16. Headings

The headings to Conditions shall not affect their interpretation.

17. Governing Law

These Conditions shall be governed by and construed in accordance with English law and the Consultant hereby irrevocably submits to the jurisdiction of the English courts. The submission to such jurisdiction shall not (and shall not be construed so as to) limit the right of the Client to take proceedings against the Consultant in any other court of competent jurisdiction, nor shall the taking of proceedings in any one or more jurisdictions preclude the taking of proceedings in any other jurisdiction, whether concurrently or not.

IO-0402A.REP

NATIONAL RIVERS AUTHORITY

FORM OF TENDER

TO: Purchasing Officer
National Rivers Authority
Rivers House
Waterside Drive
Aztec West
Almondsbury
Bristol BS12 4UD

Having examined the Conditions of Contract and the Specification/Terms of Reference, we undertake to carry out and complete the Works in accordance with the said Conditions of Contract and Specification/Terms of Reference at the rates detailed in the enclosed tender.

Unless and until a formal agreement is prepared and executed, this tender, together with your written acceptance thereof, shall constitute a binding Contract between us.

We understand that the Authority is not bound to accept the lowest or any tender that may be received.

We certify that this is a bona fide tender, that we have not communicated to any person other than the Authority the amount or approximate amount of the tender price and that such price has not been fixed or adjusted by arrangement or in collusion with any third party. We also undertake that we will not make any such communication or enter into any collusive arrangement with any third party whether in relation to this tender or a tender submitted or to be submitted by such third party.

This tender is open for acceptance for a period of .... from the date fixed for opening (minimum 30 days).

Signed .... Date ....

Name .... Tel. No. ....

For and on behalf .... Fax No. ....

....

....

APPENDIX B

Literature Review

NRA NATIONAL WATER RESOURCES STRATEGY

ENVIRONMENTAL ASSESSMENT OF STRATEGIC OPTIONS

APPENDIX B

LITERATURE REVIEW:
THE AQUATIC IMPACTS OF INTER-BASIN TRANSFER AND RIVER REGULATION SCHEMES

CONTENTS

1. International Perspective

A brief review has been made of worldwide experience of water transfer schemes and their environmental impacts, both in order to put UK proposals in context, and to see if any useful approaches to strategic environmental assessment have been developed. This section concentrates on water transfer and river regulation schemes. Environmental impact assessment (EIA) relating to reservoir construction and operation are described in the various publications of the International Commission on Large Dams (ICOLD) and World Bank (WB). Both the ICOLD and WB EIA methodologies apply a checklist and matrix approach with a strong emphasis on identifying opportunities for mitigation.

There are several collections of review papers on large scale inter-basin transfers. Inter-basin transfers exist on all inhabited continents. The most spectacular examples of man interfering with the hydrological cycle occur in North America, Russia and Australia. In Europe, there are known to be sizable transfer schemes in France and Germany, but no publications about them were identified as part of this review. Golubev & Biswas (1979) include a bibliography of 502 entries relating to different aspects of interregional transfers around the world.

Between 1977 and 1983, a series of meetings of international experts on large-scale water transfers was sponsored by the United Nations Environment Programme. The 1984 issue of the International Journal of Water Resources Development 2(2/3) was dedicated to large-scale water transfers and contains keynote papers on schemes in the USA, Canada, Russia, Sudan, China, Mexico and Hungary, compiled by Golubev and Biswas (1985).

Golubev and Biswas (1985) discuss the emerging social and environmental issues associated with large scale water transfers. They identified a need for a framework for evaluating future proposals and criticised existing methodologies, including benefit-cost analysis, and environmental and social impact assessment, for not taking an holistic approach and being descriptive rather than predictive. The Expert Group proposed that the framework should consider:

- Alternative types of transfer
- Institutional aspects (political,legal,institutions)
- Environmental impacts (physical, biological, use)
- Alternative strategies (eg demand control, re-use)
- Motivations and perceptions

They did not produce an assessment framework and their main conclusion was that accurate prediction of impacts for such complex systems was impossible and they therefore highlighted the need for post-project monitoring and evaluation.

A review paper by Shiklomanov (1985) summarises environmental problems arising from large-scale water transfer projects around the world. The scale of projects expressed in both absolute terms and as a percentage of mean annual runoff are far beyond anything likely to be proposed in Britain. In both Russia and the USA reductions in runoff from major river basins of up to 60% are reported, eg the Colorado. In Russia, transfers from the European rivers are measured in tens of km^3/year (1 km^3/year = 2740 Ml/d) and have caused significant ecological damage in catchments such as the Aral Sea and the Volga. However, the problems specific to transfers are masked by the scale of general environmental pollution.

An interesting historical perspective on the papers produced by Russian scientists in the 1970s and 1980s is that the impacts of these proposed hydrologic projects were studied using complex systems models, including all physical and biological interactions and were aimed at identifying and mitigating all adverse effects. The environmental disasters arising from these projects in Russia are now well chronicled and it can be concluded that predictive studies in themselves are ineffective unless development is accompanied by effective regulatory authority and pollution control legislation.

Details of measured impacts specifically related to transfer schemes are scarce. Day et al (1983) review biophysical impacts arising from the Great Lakes diversions in Canada, and conclude that the main effects are related to channel erosion.

Over the past decade there has been a clear shift away from engineering enthusiasm for large projects towards environmental concern. A recent cynical view is presented by Pearce (1992), in which he catalogues large-scale schemes such as those on the Colorado River as environmental disasters. Palmer (1986) describes the evolution of the river conservation movement in the USA, which now has more than 100 rivers on its "endangered" list, and actively campaigns against all large scale water resources development projects. The press which any large water resources project generates in Britain (eg article in New Scientist 20/3/93 "Water companies leaky arguments for reservoirs" on potential resource developments in Yorkshire) ensures that any promoter of large-scale transfer schemes in the UK will have to make their case very carefully.

The textbook by McDonald & Kay (1988) reviews large scale water resources projects around the world, and includes a chapter on the major issues associated with water resources management and strategies for dealing with these issues. The key issues they identify are:

- Scale
- Appropriateness
- Need for integration

These issues mirror those found throughout the literature. The larger the scale of project, the greater the potential scale of impact. They quote the recommendations of an inquiry into Federal water policy in Canada, stressing the need for integrated management involving:

- catchment management plans, taking account of all uses affecting flow and quality;
- full information on hydrological regimes;
- models capable of revealing the full range of impacts of proposed developments;
- specified management objectives for the watershed;
- participation of all regulatory agencies;
- provision for public participation in determining management objectives.

Further specific impacts associated with transfer of regulation schemes both in the UK and Worldwide are discussed in subsequent sections of this Chapter.

2. Physio-chemical Changes

The changes caused by the development and transfer of water resources are firstly to the physio-chemical system through changes in hydrology, water quality and geomorphology and secondly to the aquatic and terrestrial ecosystems through transfer of biota or in response to changes in the physical system. Figure 1 shows a simplified systems diagram of the interactions between physio-chemical systems, biological systems and user interests. In reality, the mechanisms for feedback and interdependence are highly complex.

2.1 Hydrology

This section reviews ways of classifying river reaches, flow regimes, hydrological changes caused by river regulation and transfer, and approaches to managing abstraction and regulation. To put this section into context Petts (1988a) reports that of 1310 gauging stations registered by the DoE only 11 percent record natural flows. 793 gauging stations are classified as affected by flow manipulations, abstractions and discharges. The following statistics concerning gauging stations reflect the nature of flow regulation in the UK:

- 9.5 per cent are affected by direct regulation, are augmented by water from surface water and/or groundwater storage upstream of the gauging station;
- 2.4 per cent are affected by indirect regulation to suit the needs of hydroelectric power generation;
- 25.9 per cent are affected by indirect regulation by impounding or storage reservoirs situated in, and supplied from, the catchment above the gauging station; and
- 39.3 per cent are affected by interbasin transfers for water supply. This is achieved either be abstractions from a reservoir or river intake (25.9 per cent) or by effluent return via sewage works or industrial works (26.6 per cent).

Despite the large number of interbasin transfers there are relatively few published works on the subject. There is also a lack of information on the existing transfer schemes for example the Trent-Witham-Ancholme and the Ely Ouse-Essex schemes within the Anglian Region. Possibly the most comprehensive review of the effects of the Ely Ouse transfer scheme is to be found in a 1976 edition of Chemistry and Industry (Guiver, 1976).

Reach Classification

The hydrological and biological consequences of abstraction or discharge depend upon the character of the river at the point of interference. A simple classification scheme for reaches of different characteristics given below is based on that discussed by Petts & Foster (1985) and elaborated by Gordon et al (1992):

- Upland (headwater) reaches: steep gradient; active bed and bank erosion; coarse bed material; fast flowing; rapid hydrograph response; many UK upland catchments regulated by reservoirs; water temperatures relatively cool and stable; low to moderate biodiversity; the flow regimes of upland reaches are highly sensitive to abstraction/discharge.

- Middle-order reaches: moderate flattening gradient; sediment transport from bank erosion/deposition and upstream supplies; highly variable physical characteristics and hydrograph response; variability of substrates, temperatures and discharges encourages high biodiversity; effects of abstraction/discharge depend on site specific conditions.

- Lowland rivers: slow flowing; stable discharge; usually depth regulated in the UK; beds composed of fine sediments; generally low biodiversity; generally depth insensitive to abstraction/discharge, but abstraction at low flows can have important effects on retention times.

- Tidal reaches and estuaries: discharge, velocity and depth controlled by the tidal cycle except during floods; active silt deposition; variations in salinity reflected in high biodiversity.

A further classification proposed by MacMillan (1986) and described in Gordon et al (1992) is the degree of "naturalness", which can range from natural to semi-natural to artificial. Many rivers in eastern Britain which have been engineered as drainage channels are highly artificial.

It is clear from the above categories, that abstractions/discharges will have least impact the further down the catchment they occur. The environmental optimum would be to abstract water as close to the tidal limit as possible. This would have the added benefit of requiring higher quality standards in the upstream catchment. There are risks associated with transferring water from a lowland reach into an upland reach, because of the potential disruption to the continuum of physical processes, sediment, nutrients and biota (Vannote et al., 1980) with unpredictable consequences. On the other hand, there may be the potential for environmental benefits if transfers are made into an unnatural or degraded reach by introducing sympathetic restoration (Brookes, 1988).

Classification of Flow Regimes

Blench (1969) describes flow regime as the representing the "climate" of a channel. The concept of regime encompasses the seasonality and variability of flows experienced at a particular location. For different biota, it is not the flow itself which is important, but the sequences of velocities, depths, temperatures and other physio-chemical characteristics they experience.

Gustard (1992) classifies flow regimes in terms of: duration; frequency; and seasonality. Frequency and duration statistics are essentially different ways of looking at the same spectrum of low and high flows, and they can be related by simple linear or log-linear equations (Gustard 1992). Both the timing and magnitude of high and low flows are important for different environmental receptors. A simple way of characterising the flow regime is:

- High/mean flow regime: important for channel forming processes (Richards, 1982) controlling siltation, fish migration, estuary flushing to limit saline intrusion.
- Low flow regime: important for survival of many biota, water resource availability, dilution of effluents and hence water quality.
- Seasonal flow regime: important for the growth cycles of most biota.

Simple indices are: the mean annual flood (MAF) for high flows, the bankful discharge or annual mean flow (MF) for mean flows, the 95 percentile flow exceedence (Q_{95}) or mean annual minimum 7-day flow (MAM7) for low flows. The index of low flows most commonly used by the NRA regions for setting discharge consents is Q_{95}, but since MAM7 is usually a more severe statistic, it is becoming widely accepted as a physically interpretable low flow measure, being the average flow during the lowest flow week of the year.

Hydrological Effects of Regulation

No references have been found on the hydrological effects of transfers *per-se*, although there is a large amount of literature on groundwater augmentation schemes which in principle are no different hydrologically from transfer effects in the recipient catchment. The hydrological consequences of transfer/augmentation are entirely dependent on the timing and magnitude of discharges and any flow related control rules. In general, augmentation schemes are used either to support surface abstraction at low flows or to provide dilution and maintain water quality at times of low flows.

Any form of river impoundment will change the flow regime below it. The effects upon the hydrological characteristics of the river downstream, both on the donor and recipient river, depends on two sets of factors (Petts, 1984):

- Morphometry of the reservoir basin; although this varies little in the UK due to low sedimentation rates.

- Compensation flows and reservoir releases. In the extreme case this has led to a reduction in the median flow of up to 43% of the pre-impoundment figure. However, there is a marked degree of variability reflecting the operational rules of individual reservoirs (Higgs & Petts, 1988).

Interbasin transfers may contribute to increasing flood peaks on the receiving river while the donor river may experience a reduction in flows particularly if an H.E.P scheme is in operation (Roy & Messier, 1989).

There are specific hydrological impacts of reservoir construction and compensation discharges. Detailed studies of hydrological changes associated with reservoir construction and operation in the UK are reported by Gustard et al (1987) and Higgs & Petts (1988). Gustard et al (1987) studied the flow regimes before and after reservoir impoundment. They describe the historical background to setting reservoir compensation flows and identify that the needs for which compensation flows were set have often changed significantly, and there may therefore be considerable scope for both improving resource yield and maintaining a healthy downstream environment. Of the 261 reservoirs studied, 70% release a constant discharge, although some also release artificial floods or freshets for fisheries reasons. Others release so as to maintain a minimum flow at some gauging station downstream, whilst the remainder have seasonally varying releases, usually summer high/winter low. The average compensation flow was 16% of the MF, and the MF downstream of the reservoir was 55% of the natural flow without impoundment. They found that the artificial influence of the reservoir on the natural flow regime downstream is negligible where the reservoir catchment is less than 10% of the total catchment.

The greatest reduction in flows occurs in the mid flow range Q_{10} to Q_{90}. Although on average compensation flows were 22% higher than Q_{95} for natural conditions, there was considerable variation from 0% up to more than 500% of natural Q_{95}.

They made a detailed assessment of the magnitude and timing of high flows with and without the reservoirs based on 29 sites, which showed that both the magnitude, timing and frequency of spates changed. The MAF was not reduced significantly, but the frequency of spates (defined as 2x or 5x the MF) was about 30% of that which would occur in the natural river. The other key effect of impoundment is that summer and early winter spates are captured by the reservoir as it fills. This can have important implications for fisheries. Higgs & Petts (1988) found that the MAF was reduced by about 30% for the River Severn following construction of Clywedog reservoir, but they hypothesised that this was as much due to climate change as to the reservoir effect.

Extreme low flows have been eliminated by river impoundment and interbasin transfers. Yet while the monthly minima have been increased in the summer they have been reduced in the winter in many regulated rivers. This has meant that there has been a flattening of flow duration curves (eg Hadley et al., 1987). The ecological effect of such operations can clearly modify the habitat and it is possible that the transfer of water from one catchment to another may cause confusion to returning migrant species, especially salmonids (Hellawell, 1988).

Management of Flow Regimes

In the context of water resources management in the UK four low flow criteria are used for controlling abstractions and discharges so as to limit environmental damage: minimum acceptable flow; prescribed flow; maintained flow; and minimum residual flow to estuaries. In addition, some reservoirs, particularly in Scotland and Wales, make high flow releases or freshets for migratory fisheries.

The notion of a minimum acceptable flow was introduced under the Water Resources Act 1963. The minimum acceptable flow was to be specified at control points so as to safeguard the requirements of existing lawful uses of watercourses. Wood (1981) explains why they were not routinely applied because of problems in relating flow and level to environmental parameters. The main aim of setting minimum acceptable flows was to ensure no derogation of existing abstraction rights.

A prescribed flow (PF) is a flow at a gauging station referred to in a new licence such that abstraction must cease whenever the river flow is below the PF. The PF is a way of protecting the river from excessive abstraction. Unfortunately, Licences of Right granted under the 1963 Act were not subject to such restrictions. In addition, the complexity of linkages between surface and groundwater together with a lack of defined environmental objectives have meant that many new groundwater and surface licences have been granted without regard to a PF in an integrated manner. It is understood that any new abstraction or discharge licenses granted by the NRA will be time limited and subject to a prescribed flow to protect downstream user interests and environmental needs.

Maintained flows are the basis for compensation flows from several reservoirs in Yorkshire, eg Worth Valley reservoirs near Keighley. Like constant compensation releases, these were usually set to maintain flows for industrial requirements which often no longer exist.

A recent report by the NRA, Severn-Trent Region (1992) reviewed the variations in regional practice for determining minimum residual flows (MRF) to estuaries. MRFs are set either as an annual figure, based on winter/summer seasonal requirements or based on tidal conditions. Significant variations in policy were found, with the wetter west tending to try and maintain existing low flows as measured by Q_{95}, whilst the drier eastern regions even contemplating a zero residual flow, such as for the Yorkshire Derwent.

Of the 67 estuaries investigated, 30 had some form of MRF, which ranged from 0.24 to 1.38 times the Q_{95} dry weather flow for annual MRFs and 1.08 to 8.5 times Q_{95} for winter/summer MRFs. The requirements cited for determining MRFs included: fish migration and survival; quality needs for abstractions near the tidal limit; dilution to maintain quality class; navigation; amenity; and ecology. The main quantitative factor for setting MRFs was for abstractions near the tidal limit. Although some studies have been used to set MRFs for environmental reasons based on mathematical models or fish migration studies, most MRFs have been set empirically. Rivers with migratory fisheries generally have an MRF of at least 50% of Q_{95}.

In the UK, the first systematic attempt to introduce an environmental prescribed flow (EPF) as a basis for assessing licence applications was by the then Yorkshire Water Authority (YWA), as described by Drake & Sherriff (1987). They proposed a relatively simple method of using different weightings for six environmental categories: fisheries, angling, aquatic ecology, terrestrial ecology, amenity and recreation. These weightings were used to determine EPFs when granting new surface abstraction licences. The EPF was expressed as a proportion of MAM7. They also proposed a river quality prescribed flow (RQPF) at key points in the river system to ensure that downstream water quality would not be lowered as a result of increased upstream abstraction.

There are relatively few examples of integrated approaches to setting acceptable flow targets for the full spectrum of environmental requirements, covering both minimum flows, aimed at maintaining sufficient habitat, acceptable temperatures, and depth for the passage of fish; and intermittent high "flushing" flows to remove fines from the streambed, scour encroaching vegetation, and flush anoxic or saline water from stratified pools. Tunbridge & Glenane (1988) (cited in Gordon et al, 1992) specified four flows for the management of a regulated river and estuary in Australia:

- Optimum environmental flow - for full fish production and recovery after drought.
- Minimum environmental flow - resulting in negligible reductions in fish stocks in average rainfall years;
- Survival environmental flow - may cause a reduction in fish stocks, but no loss of species
- Flushing flow - to remove fines from the streambed, maintain the freshwater reach, remove the salt wedge in the estuary.

In recent years, the terms Ecologically Acceptable Flows and Environmentally Acceptable Flows (EAF) have been introduced, eg Bullock and Johnson (1991) and Brown et al (1991). The implication is that ecological or more general environmental needs should be assessed independently of existing levels of resource development. If followed through to its logical conclusion, this could result in the NRA revoking existing abstraction licenses to restore acceptable flow conditions.

A recent comprehensive review of methods for setting EAFs is given in Gordon et al (1992). The two approaches to setting acceptable flows are:

- Discharge related methods ("rules of thumb")
- Habitat related methods

Discharge related methods define the EAF in terms of a proportion of some measure of the existing flow regime. Examples are as a percentage of the mean flow (MF); the Q_{95} flow duration statistic; or a low flow frequency statistic, eg the MAM7 or 1 in 10 year drought 7-day flow. The Montana method is used widely in the USA to protect fisheries by setting the EAF as 30% MF at migration time and 10% MF at incubation time. This is an extremely simple method to apply. Although the method proved effective in the USA it is uncertain whether it is appropriate for use in conditions hydrologically or morphologically dissimilar from those for which it was derived.

A more elaborate method developed in the USA and New Zealand is habitat simulation. The Instream Flow Incremental Methodology (IFIM) has at its core a computer model for Physical Habitat Simulation (PHABSIM), see descriptions in Bullock & Johnson (1991), Orth & Leonard (1990). This method requires measurements of water depth, velocity and water surface profiles for several cross-sections at a range of flows. The simulation is then run in increments of flow to predict the biological response of fish, macroinvertebrates and macrophytes to the available habitat. When calibrated for UK conditions, IFIM will provide an important planning tool for deciding minimum flow requirements and could be used at the stage of a detailed EA to compare the environmental implications of different proposals. The latest applications of IFIM use salmonids as the key indicator species for setting EAFs (Johnson et al, 1993).

An important conclusion from the Gustard et al (1987) study is that there is no reason why a healthy aquatic environment cannot be maintained downstream of reservoirs provided the artificial flow regime is set with some reference to the natural flow regime to which the ecosystem has evolved. Hellawell (1988) argues that river regulation causes irregular and intermittent modification to the natural flow regime to which a community is well adapted, and therefore will inevitably cause a loss of diversity and species richness. The general conclusion seems to be that changes from historic flow regimes should be as little and as gradual as possible to minimise adverse environmental effects.

For a strategic EA, with the level of detail of hydrological information that will be available for making judgements, some form of simple "rule of thumb" approach would seem to be appropriate, using the existing flow regime as a reference point.

2.2 Water Quality

This section reviews the accepted and practised ways of classifying river water quality, the principal water quality parameters, and the water quality changes associated with regulation (groundwater recharge and reservoir) and transfer (pipeline, canal and river).

Classification of Water Quality

Surface water reaches have been classified according to water quality for many years. The main chemical determinants used in the National Water Council (NWC) Classification are biochemical oxygen demand (BOD), dissolved oxygen (DO) and ammonia, expressed as 95-percentiles, in addition to water quality capable of supporting different types of fish and/or potable water supply if appropriate. Since the 1989 Water Act, Statutory Water Quality Objectives (SWQOs) are being introduced, incorporating Use-related Classes and the existing EC Directive requirements where appropriate. Increasingly the biological status of the river is used to assess river health, including water quality parameters.

Estuarine classification was historically based upon the water quality parameters of biochemical oxygen demand and dissolved oxygen; changing in 1980 to a subjectively assigned point-scoring system based on water quality, aesthetic quality and biological quality. A new, less subjective classification based upon water quality (dissolved oxygen, ammonia, nutrients nitrogen and phosphorus), sediment quality (Black and Grey List compounds adsorbed to fine particulates), aesthetic quality and ecological quality is proposed as part of the SWQOs.

The temperature regime of the river is considered by many to be one of the most important factors controlling riverine ecology. In many studies of river temperature zonation and classification, the range and variance of water temperature are of significance, rather than the mean monthly maxima and minima (Hellawell, 1986). Naturally, the temperature characteristics of a river are dependent upon many factors, most important of which are water flow and riparian vegetation management.

Principal Water Quality Parameters

It is well documented that the upland and upper-middle reaches of a river have a fundamentally different chemical make-up from lower reaches (Hellawell, 1986). Upper reach waters are well oxygenated, usually with a low BOD, low temperatures, and a small loading of suspended sediments. Conversely, lower reaches have lower oxygen levels, a greater natural and man-made BOD, and a greater loading of suspended sediments. The dissolved oxygen/BOD loadings fundamentally affect the biotic component of the river, and also influence the setting of discharge consent levels. Any transfer of unmixed water from the lower reaches to upper reaches, even of the same river, will greatly affect water quality.

Water temperature has a profound effect on river biology and chemistry. The 24 hour variability (diurnal variation) of water temperature is often the critical cue for stream organisms, although data collection is not usually conducted at this level of detail. Experience from the Welsh Dee and Tyne-Tees transfer schemes suggest that water temperature might be the most important parameter limiting fish stocks.

Levels of suspended sediments are affected to a great degree by the geology and morphology of the catchment (Roy and Messier, 1989), and are more variably related to flow. Suspended solids, whether organic or inorganic, tend to adsorb metals and organics such as biocides to their surfaces, thereby affecting water chemistry in addition to the physical effect of increasing turbidity.

Countrywide variations in solute concentrations relate to hydrometeorological and physiographic variations across England and Wales (Petts, 1988a). Total dissolved solids, for example, tend to be highest in the east (1200μS/cm), and lowest (35μS/cm) in the west and north. Chloride and nitrate concentrations also tend to be highest in the east. Interestingly, due to the regional differences in rainfall, the greatest mean annual loadings of chloride and nitrate to estuaries are highest to the west and north (Petts, 1988a).

Average pH levels of lower than 7.0 and occasionally as low as pH 5 characterise upland streams in the west and north with base deficient soils which afford little buffering capacity; whereas the calcareous soils covering large areas of eastern and central England can give rise to streams with pH values greater than 8, more commonly between 7-8 (Petts, 1988a).

The upper reaches of rivers throughout England and Wales are considered to be nutrient poor (oligotrophic), and derive much of their organic and nutrient input from sources external to the water body. Their nutrient status is dependent upon the catchment land use. Lower reaches of rivers are invariably nutrient enriched, having received nutrients from both sewage treatment works and from farmland run-off in addition to the recycling and retention of autochthonous (internal) nutrients within the river biomass. There are obviously case-specific exceptions to these generalisations, with the oligotrophic status being comparatively rare in England, and nutrient enriched waters being common.

A serious consideration in inter-catchment water transfers is the transfer of pollutants such as metals and biocides, or the alteration of recipient water characteristics such that previously inert compounds become toxic. This is particularly serious when water uses differ between donor catchment and recipient catchment. The most obvious examples are associated with irrigation, eg the transfer of the herbicide 2,3,6-trichlorobenzoic acid within the Ely Ouse-Essex scheme, the transfer of salt-rich waters, or the alteration of pH, mobilising metal ions.

A further concern is the possibility of transfer of accidentally spilt contaminants, thereby polluting two river courses. The type of spill is partly a function of the catchment use: an industrialised catchment being more prone to chemical or oil spills, whereas a rural catchment is more prone to organic overflows; and partly a function of the river length above the abstraction point; the greater the river length, the greater the probability of a spill.

Water Quality Responses to Changes in Water Regulation

Water regulation is achieved by either above ground storage in reservoirs, which may be on-line or off-line (in which the filling and drainage behaviour is governed by a watercourse which does not pass through the storage area), or by recharge using groundwater.

The advantages and disadvantages of reservoirs are well documented, and will be only briefly reviewed here, particularly as engineering options exist to mitigate many of the disadvantages. The benefits include the settlement of large sediments, with associated nutrients, metals and organics, and the provision for water blending. Disadvantages include water stratification, with a lower, cold, oxygen-depleted hypolimnion which is often rich in dissolved iron and manganese, and high levels of organic matter and suspended solids (Hellawell, 1988).

Releases of hypolimnetic water can affect river water for many kilometres downstream. The temperature regime below reservoirs can be greatly altered, leading to the concept of "thermal resetting" (Crisp, 1985). Studies on water temperature immediately downstream of Kielder Water have shown that the amplitude of monthly mean temperatures are reduced by almost 6°C when compared to river water. The mean diurnal range was 1.5°C lower (drops of 0.8 to 2.1°C were recorded), the summer peak temperature was depressed by 3.7°C and delayed by 4-6 weeks, and the winter minimum temperature was raised by 2.6°C and delayed a month (Crisp, 1985). The rate of equilibrium varies, but for modest impoundments in England is expected to be within a few kilometres downstream of the release (Crisp, 1985). Webb and Walling (1993) report that the main effects of river regulation on water temperature are to increase the mean value, eliminating freezing conditions, depressing summer maxima, delaying annual cycles and reducing diel fluctuation over a distance of 5km. However, the temperature impact will decline with distance downstream.

The effect of nutrient loadings, in particular phosphorus, in the input waters may be minimised by lacustrine sediment settling. However, shallow reservoir waters in particular give the potential for eutrophication and algal blooms, which cause oxygen depletion, affect turbidity and colour, and possibly lead to toxin releases in the case of Cyanophyte species.

Even water storage in on-line reservoirs can modify water quality. In storage, chemical exchange and cycling occur in conjunction with biological degradation and uptake, such that water leaving storage is likely to be of a different character from that entering in terms of water chemistry, temperature and suspended solids (Higgins, 1990). For example, studies on the River Fly and Lake Bissett system in Papua New Guinea showed that the reservoir water was more acidic, with an average pH of 6.4, while river pH averaged 7.4. Dissolved organic carbon levels in Lake Bissett were 6-9 mg/l, while values in the Fly River were 3mg/l (Higgins, 1990).

A primary problem associated with the use of groundwater is the constant, relatively low temperature (about 10-11°C) which suppresses both diurnal and annual variation, lowering the mean summer temperature, and raising the mean autumn and spring temperature of the recipient river (Brewin and Martin, 1988; Hellawell, 1988). Furthermore, groundwater has a lowered dissolved oxygen content, elevated dissolved nitrogen and elevated nitrate and iron concentrations (Hellawell, 1988). Alternating desaturation-resaturation cycles within the aquifer can affect oxidisation of minerals and mobilisation of salts and metals.

Water Quality Responses to Changes in Water Transfer

Water transfers between catchments are envisaged to be by pipeline, river or canal. As discussed above in the section on water quality parameters, there are general water quality changes from east to west in England and Wales. Extreme examples of water transfers would involve transfers between acidic and calcareous catchments, with associated changes in acidity, hardness, etc. A second extreme example would involve water transfer from the lower reaches of a river, water relatively high in nutrients, BOD, suspended sediments, etc, to the upper reaches of a watercourse where the water is typically low in nutrients and high in DO.

Canals and pipeline water transfer give rise to unique concerns. In general, canal water is of lower quality than river water, due to the reduced rates of turnover and less efficient aerobic processes. Chemical parameters such as nutrients and BOD are usually elevated, temperature is high and DO is relatively low. Using canals for water transport routes will modify the quality of the donor water, and there is a risk of flushing low quality water into the recipient waterway. Furthermore, canal maintenance and dredging risk disturbing sediments high in contaminants in addition to being anaerobic, which may be flushed into the recipient river.

In pipelines, there is the possibility that water with a high BOD will become anaerobic, that solids will be deposited, that acidic water will corrode the pipe, and that carbon dioxide or hydrogen sulphide will be released. With adequate controls, such changes in water quality should not occur. Draw-down of the pipeline during non-operational periods will minimise the growth of organisms (eg slime, zebra mussels) on the inside of the pipe, and will prevent the build up of stagnant, anaerobic water. Care should be taken to empty the pipeline before such conditions occur, and washouts must be planned for sections of the pipe that cannot drain to the donor or recipient rivers, ensuring that local watercourses, which may be only drainage ditches, are not affected.

However water is transferred, some general principles apply. Firstly, there are water quality parameters which are affected along a "continuum", experiencing an elevated (+) or lowered (-) level to a greater or lesser degree such as pH, DO, temperature, nutrients and hardness. Secondly, there are the "presence/absence" type of considerations: moving algae (which may influence water quality by depressing DO, raising BOD, affecting turbidity and releasing toxins), spreading pathogens and transferring contaminants. A third consideration appears to be a "composite" water quality measure, that is changing the chemical fingerprinting of rivers.

Mixing

Concern over the decreasing water levels and lower dilution capacity in the donor river with the concomitant increasing proportion of effluent in the river have been expressed (Brewin and Martin, 1988). Discharge consents have been based on mass balances and dilution capacity, as well as the downstream river quality objectives of the receiving water. It has been found more economic to achieve a given river quality objective by improving effluent treatment rather than by stipulating increased river flows (NRA, Anglian Region, 1993a), thereby opening the way for potential reductions in donor river flows.

Residual flows have been set for estuaries, many of which are based on effluent dilution and water abstraction needs near the tidal limits, although some residual flow levels have also been set for environmental requirements. The characteristics and contours of the saline wedge, the degree of mixing/stratification, and levels of dissolved oxygen, ammonia and nutrients are important parameters in estuarine water quality. The partitioning of metals between the solid and liquid phases is also affected by salinity, thus the metals balance in an estuary can be influenced by freshwater flow (Alabaster, 1976). Although there is an argument that there is less need for river water for dilution as the quality of discharges into the estuaries are improved (Brewin and Martin, 1988), the saline wedge characteristics are also greatly affected by freshwater discharge, and in their turn fundamentally influence biotic zonation in the estuarine ecosystem.

Predictability

Despite the generalisations about water quality parameters stated above, river water quality can naturally change very quickly and significantly as a consequence of heavy rainfall on a catchment causing high run-off (Johnson, 1988). Particularly in upland catchments, the colour, acidity and suspended sediment loading can greatly increase after rainfall; and the first major winter storm, the freshet, results in a high loading of nutrients from farmed land and metals and oil from urban catchments.

A little understood aspect of river water quality is chemical fingerprinting, consisting of either the chemical make-up of the river or pheromones, uniquely identifying rivers to migratory fish. This fingerprinting remains identifiable from year to year, indicating a high degree of predictability in this composite aspect of water chemistry,

In addition to problems associated with sampling error, which may be corrected with appropriate statistical tools, water quality exhibits naturally occurring temporal patterns. The annual cycle, measured by monthly samples, is relatively well understood, as are the seasonal cycles. The variation within these cycles can also be approximated with sufficient sampling. The daily cycles are not routinely measured, and may be critical as biotic cues. Furthermore, often the minima and maxima determine species ranges, for example, parameters such as maximum summer and minimum winter temperatures, minimum DO, maximum levels of a chemical. Data at this level of detail are generally unavailable since current water quality monitoring programmes rely more on establishing the general water chemistry through time periods of years. The best method to assess the living state of rivers, integrating all factors including water quality through the many temporal scales, is to use biological indicators/biological class.

2.3 Geomorphology

Sediment Transport and Instream Hydraulics

Damming modifies the physical processes that form and transport the natural substrate of the river. A reservoir will hold fine sediments within it so that bedrock may be exposed below the dam, although reservoir cleaning operations will introduce fines to the downstream reaches (Carling, 1988; Petts, 1988b). Spates or floods may remove surface gravels but the dam prevents their replenishment. The river response is directly proportional to the magnitude of the altered hydrological regime and while some areas close to the dam experience degradation, others may experience aggradation as well as channel contraction (Sherrard & Erskine, 1991). Degradation of the channel appears to be the most immediate response to regulation. Long-term changes appear to be more important, with channel instability and aggradation being the dominant response (Carling, 1988). This variation can lead to a drastic alteration of the instream habitat and biotic communities. The degree of change depends on the distance from the dam and the distribution of tributaries along the river from which replenishment of substrate and biota recovery can occur (Storey et al., 1991).

Petts (1988b) found that in the River Daer, Scotland and the River Derwent, Derbyshire, the proportion of fines (sub-2mm) by weight within a gravel substrate, were elevated within two reaches.

- Between the dam and the first tributary confluence.

- For about 2.5km below a tributary confluence. (Similar results were also reported by Carling (1988)).

Both the proportion (20 per cent, by weight, below the tributary confluence compared to less than 5 per cent for non-regulated sites) and size of the fines within the substrate decreased from the confluence and as a result the ecological impact of substrate sedimentation is likely to be localized, close to the dam. Davey et al. (1987) found that sediments within the range of 0.063-2mm were deposited within a 10km reach below the dam and that finer silts and clays could be detected nearly 30 km downstream.

Regulation by dams in the UK results primarily in reduced stream power expenditure and decreased channel capacity through lateral shoaling (Carling, 1988). Channel capacity downstream of a storage reservoir still needs to accommodate a large proportion of the volume of large floods to prevent flooding and morphological adjustments of the channel and floodplain. However, flow reduction as a result of river regulation means that channel capacity is no longer self maintaining, capacity is reduced, bed roughness may increase and stream velocity decreases. The recipient stream in an interbasin transfer may conversely experience a long-term increase in flow velocity (Boon, 1988).

Petts et al. (1993) suggest that the variation of ecological impacts between riffles relates to site-specific hydraulic conditions, especially bed shear stress. Since regulation began on the Platte River, Nebraska, there has been a reduction in channel scour (Hadley, et al., 1987). Originally the Platte River channel was wide, relatively shallow, and devoid of dense vegetation. The onset of a minimal flow throughout the year has encouraged vegetation growth and the deposition of sand bars. This has been accompanied by a reduction in the channel width which has been enhanced by the vegetative stabilisation of these large sand bars that have gradually evolved in to islands. Many of these results were replicated in Mangrove Creek, Australia (Sherrard & Erskine, 1991).

The effect of water transfers on the recipient rivers of the La Grande Hydroelectric Complex (Quebec, Canada) (Roy & Messier, 1989) caused massive bank erosion of the normally exposed banks of the rivers with increased flow. Erosion of these new banks accounted for 52 per cent of 120,000m^3 of the material eroded. This figure reduced in the following years and only three years after vegetation cover was 80-90 per cent. Bank erosion on rivers with increased flow was also markedly increased although this again was relatively short lived, and ceased once sediments were exhausted.

From this short review it is clear that each reservoir-river and interbasin transfer system is unique. Climate, geology and operational regime combine to produce a response that can not be used to construct a simple generic model of channel change.

3. Biological Responses

3.1 Aquatic Ecology

There has been a marked increase in theoretical literature on natural river systems over the last fifteen years (Cummins, 1979; Vannote et al., 1980; Junk et al., 1989; Ward, 1989). There has also been widespread recognition that the majority of the world's rivers have been regulated (Ward & Stanford, 1983; Petts, 1984). The dominant influence of anthropogenic influences has led to the questioning of the applicability of many ecological concepts, such as the River Continuum Concept (Statzner & Higler, 1985; Fruget, 1991), and to the development of theories to explain the ecology of regulated rivers (eg Ward & Stanford, 1983). Four types of river regulation have been identified (Petts, 1988a) and their effects on the fluvial environment and ecology considered:

- Mainstream impoundments (eg Petts, 1984; Tuch & Gasith, 1989; Sherrard & Erskine, 1991.
- Interbasin transfers (eg O'Keefe & De Moor, 1988; Roy & Messier, 1989; Davies et al 1992, Dudgeon, 1992).
- Pumped storage reservoirs (eg Petts, 1988a; Casado et al 1989)
- Groundwater abstractions (eg Wright & Berrie, 1987; Armitage & Petts, 1992; Bickerton et al., 1993).

Probably the best definition of those water transfers likely to cause an ecological impact is: "the transfer of water from one geographically distinct river catchment or basin to another, or from one river reach to another." (Davies et al., 1992). All transfers of water will have chemical, hydrological, physical and biological implications for both the donor and receiving streams. Davies et al., (1992) suggest that interbasin transfers (IBTs) disrupt the river continum (Vannote et al., 1980) in a similar way to the Serial Discontinuity Concept (SDC) (Ward and Stanford, 1983). A lack of ecological data is evident from consideration of examples from south-eastern Africa, southern Africa, and the central and south-western parts of the United States. From this study and others directly relating to IBTs (O'Keeffe & De Moor, 1988; Roy & Messier, 1989), and other studies relating to river regulation, the following ecological effects and factors influencing the degree of impact have been identified.

The Effect of Interbasin Transfer and River Regulation on Biota

There are several review papers that consider the impact of river regulation, including interbasin transfers, on biota in the UK; fish and fisheries (Mann, 1988) and invertebrates (Boon, 1988). There is at present no clear information on the effects on aquatic macrophytes.

Riparian Vegetation

Riparian vegetation provides an important source of organic matter for ecosystems, sites of shading for fish and is important for insect emergence and resting (Hellawell, 1988). The loss of riparian vegetation particularly during the construction phase of a scheme and for the maintenance of the channel may have consequences for the submerged biota.

Nilson et al. (1991) found that the presence of pre-regulation river margin vegetation relates to water-level regime. The frequency and duration of flooding is important for growth and regeneration (Bren, 1988); the height of river margin and mean annual discharge were the most important determinants of species richness, which was greatest in natural sites and in regulated sites with remnants of pre-regulation vegetation. Water level regime, mean annual discharge and substrate particle size were most important for plant cover; with the highest percentage ground cover in natural sites with a fine substrate.

Primary Production and Food-Webs

Palmer and O'Keefe (1990a) found that more than 95 per cent of the particulate matter transported in a small river in South Africa with multiple impoundments, was ultra fine (80μm). The ratio of CPOM:FPOM (Coarse Particulate Organic Matter: Fine Particulate Organic Matter) in transport decreased with increasing stream order as a result of inputs of FPOM from pollution and from plankton blooms from the reservoirs. The downstream effects were largely dependent on the quality of inflowing water and the type of reservoir release. Surface-released water carried relatively low concentrations of suspended material (11-66 g/m^3). In marked contrast bottom-released water was usually sediment laden (36-190 g/m^3). It took between 4-8km downstream for zooplankton densities to reduce by 95%, although in one polluted impoundment it took between 32-35km to be reduced by 95%.

The clarifying effect of reservoirs, noted above, and the increase in mean water temperature over the year increases the primary production of algal populations. This means that although suspended matter derived from catchment sources may be reduced below the impoundment, organic matter may be at a similar level due to increased primary production. Some of the flora may be foreign to the river as a result of the lake-like conditions and/or as a result of the transfer of species from one basin to another. These can provide an important additional food source for invertebrates and fish (Hellawell, 1988).

The stabilization of low water levels can dramatically change the distribution and increase productivity of aquatic macrophytes below the impoundment (Peck & Smart, 1986). Temperature change can also have marked effects. Significant changes can occur in the epiphytic diatom community between 12°C and 18°C (Blinn, et al., 1989). 18°C appears to be the key temperature for zooplankton communities (Urabe, 1989). It is likely that surface release reservoirs or selective depth withdrawal could be used to increase the water temperature to produce a qualitative change in flora and fauna.

Invertebrates

Interbasin transfer can potentially transport different invertebrate species form one catchment to another (Davies, et al., 1992). This could have serious implications for the food chain and survival of the ecological integrity of some rivers. Alien species may establish themselves and displace native species.

The response of different families of invertebrates and communities varies. A large volume of literature exists describing the effects of river regulation on different invertebrate communities (eg Armitage et al.; 1987; Voelz and Ward, 1990; Petts et al. 1993) and some invertebrate groups: Ephemeroptera (Mayflies) (Brittain and Saltviet, 1989) and Plecoptera (Stonefly) (Stanford and Ward, 1989) in most cases are reduced in number or are eliminated below dams (Boon, 1988) and Trichoptera (Caddisflies), particularly net spinning filter feeders, appear to increase in density below dams (Hauer, et al., 1989; Voelz and Ward, 1992) especially if there is an epilmonial release (Boon, 1988). However, the response of any single species will relate to the specific, and often unique, set of factors that it experiences in the regulated river.

Disturbance During Construction

The construction process is likely to increase the possibility of accidental pollution of the river. Physical disturbance is likely to increase turbidity which, in turn, will result in a decline in aquatic macrophytes as light is reduced, and filter-feeding macroinvertebrates. Sediment deposition may occur and in extreme cases may blanket vegetation stands (Hellawell, 1988) leading to changes in the benthic invertebrate community that rely on clean interstitial spaces, which are lost by sedimentation (Marchant, 1989). Channel capacity may be enlarged to accommodate transferred water in the recipient catchment. This will probably reduce depth under dry weather flow, increase channel width, and change water velocity for a given discharge (Hellawell, 1988).

3.2 Fisheries

Spawning

Work on the rivers Lune, Avon, Frome and Welsh Dee reported by Brayshaw (1966), showed that salmon spawn naturally at depths of 0.3 to 0.8 metres and at velocities of between 0.44 to 0.97 m/sec. At velocities above 3.66 m/sec spawning is inhibited.

Crisp (1985) carried out a detailed investigation on silt transport and the deposition and survival of intragravel stages of salmonids, and the associated problem of gravel movement and egg washout. In general, high flows may lead to washout of eggs and alevins from the gravel beds, while prolonged low flows may allow sediment to seal gravel interstices and reduce oxygen supply to the redds. Crisp and Carling (1989) showed that salmonids generally avoid spawning in water shallower than their own body depth or at velocities less than approximately 0.2 m/sec.

Le Cren (1961) showed that a river can support only a certain density of fish, as fry and parr establish territories with the excess being forced downstream into more unsuitable areas, with increased mortalities. On some upland streams, flow variations may reduce egg densities to suboptimal levels at which this density dependent mechanism for controlling fry populations no longer operates.

The effect of water velocity on the downstream movement of recently emerged salmon and trout parr in experimental channels has been studied in detail by Crisp (1985). The rate of downstream movement of trout was highest at velocities of 0.4-0.7 m/sec while the maximum rate of salmon movement occurred at low velocities of 0.07 m/sec.

Cowx & Gould (1989) studied three rivers in the upper Severn catchment to assess the influence of regulation strategies on the Atlantic salmon and brown trout populations. In the regulated Afon Clywedog, juvenile recruitment of both species declined steadily following increased utilization of the impoundment for regulations. The decline was considered the response to the variable and rapidly changing discharge regime adopted in the river. Spawning success and juvenile survival of salmonids in the Vrynwy was relatively stable suggesting the flow regime in this river was less devastating. Crisp et al. (1983) found that regulation of the River Tees enhanced brown trout and bullhead populations.

Upstream Migration

Alabaster (1970), studying 6 years of fish count data for the River Coquet, Northumberland and other published data, found that salmon move at flows higher than the available median, but could find no preferred flow for all the rivers. Stewart (1968, 1969) identified a migratory flow range from 0.008 cumecs/metre width to 0.18 cumecs/metre width of river. Peters et al (1973) found maximum migration occurred at flows between 0.5-4.0 times the average flow; Brayshaw (1966) quotes 0.7 to 1.5 times average flow. In 10 years of fish count data on the River Frome Hellawell et al (1974) failed to show any relationship with flows. The release of artificial freshets from a reservoir has been successful in stimulating the ascent of salmon in some river systems (Banks, 1969; Huntsman, 1945), but their value has yet to be proven scientifically. Natural spates are more successful than artificial releases and fish are known to move without freshets or even during reduced flows (Allan, 1966). Pyefinch et al (1965) regard freshets as useful only if they prolong a natural spate. However, studies of the effectiveness of artificial flood releases are complicated by the varying numbers of fish which are available to migrate throughout the season. Less attention has been paid to the required size of peak flow, or duration or frequency of freshets. Most fish move on the recession rather than the peak flow (Stewart, 1968; Menzies, 1958; Huntsman, 1945).

Provided flow rates are sufficient for migration, then other factors such as time of day, water temperature and turbidity will influence fish movement. Hellawell (1974) states that under clear river conditions movement is generally at night, while in turbid conditions salmon will move during the day. Both Stewart (1968) and Allan (1966) report increased movement at night, although light is required for the fish to ascend obstacles.

Estuarine Movements and Entry into Freshwater

There are few direct observations on salmon entering from sea. Limited evidence from the Fowey (Potter, 1988) and Avon (Frake and Solomon, 1990) indicate that salmon arrival in the outer estuary coincides with late ebb or early flood.

Movement up into freshwater seemed to be critically dependent on occurrence of adequate river discharge, whilst no common threshold was evident. The Avon study demonstrated that tendency to remain in the lowermost non-tidal reaches was associated with discharges less than 13 and more than 10 cubic metres per second (m^3/s) respectively.

At times of low discharge salmon accumulate in the estuary, possibly leading to high net catches, or they return to sea. Insofar as salmon are unlikely to move up beyond the saline limit if discharge is too low the upper part of an estuary represents a critical zone where a 'decision' to move is made.

The advent of radiotracking has brought a greater insight into salmon responses to river flow and will improve interpretation of the extensive database available from fish counters. As most of this work is still progressing firm conclusions have yet to be reached, but some general principles are being confirmed or revised, as follows:-

- Generally, median flows used for migration on spate streams are higher than median available flows. The reverse can obtain on groundwater fed rivers (Welton et al., 1990).

- Low flows and big floods inhibit movement. Within this migration band (Cragg-Hine, 1985) the size and timing of flow variation required to support migrations is very variable between rivers, seasonally and between years on any one river.

- Summer spates are essential to bring fish up from estuaries, but have a far less predictable effect on fish already in the river. During the quiescent phase there seems to be a large pool of fish that will not respond to spates. Perhaps their inclination to move is related to distance from their intended spawning area. Paradoxically, the movements that do occur are commonly associated with spates. Thus for the majority of fish, flow variation (fish move on rising and falling hydrographs) seems to be a necessary but not always sufficient condition for movement. Fish in big spate rivers such as the Dee and Spray, or groundwater fed rivers such as the Avon, appear more inclined to move independendy of flows than those in smaller spate rivers such as the Tamar. This could be a function of channel dimensions under low flow conditions.

- Flow patterns supporting movement seems to be similar to those maximising angling catch (because catchability is greatest in moving fish). This is important because if it proves to be a reliable conclusion, then rod catch statistics may be valuable in preliminary assessments of in-season flow requirements.

- Whereas river discharge is the variable normally measured, the proximate factor(s) stimulating movement may be merely associated with discharge, eg turbidity, colour, suspended solids, chemistry, velocity. There are still no data allowing separation of the several variables changing with flow. Whilst scientifically frustrating this may not matter in practice, providing discharge bears a constant relationship with the controlling variables. However, under certain circumstances, such as reservoir release or pollution, this could break down; it will therefore be of value to understand the roles and relative importance of the various stimuli.

Minimum Acceptable Flows

The consideration of a Minimum Acceptable Flow in the setting of prescribed or compensation flows below impounding reservoirs, surface abstractions or regulation schemes, has largely been founded upon discharge statistics in the UK, applying the concept of a Dry Weather Flow. Statistics commonly used include fixed percentages of the mean flow, the 95 exceedence percentile or mean annual minimum low flows.

Attempts to quantify the varied flow requirements of fish have been relatively rare and confined to the more demanding requirements of migratory species. It is generally agreed that a single constant discharge cannot satisfy the varied annual requirements of migratory fish such as salmon, and a seasonally varied flow regime is preferred. Baxter (1961) proposed variable compensation flows below dams based on seasonal needs of fish in fifteen rivers in UK. His recommendations have been adopted on several Lothian reservoirs, such as Fruid and Westwater. Seasonally varying releases are expressed as percentages of the average daily flow in order to provide adequate flow and bottom coverage for different sizes of rivers. He considered the minimum flow requirement to maintain healthy conditions for aquatic life, including the food supply of fry and parr, could be met by the dry weather flow, subject to a minimum flow of 12.5% ADF in dry periods. In addition Baxter suggested that for upstream movement in spring, salmon required flows of 30-50% and 70% of the ADF in lower/middle reaches and upper reaches respectively. These freshet releases would need to last for 18 hours only, of which 12 hours would be at the full rate, followed by 6 hours in which the flow was gradually reduced. His recommendations, though based on extensive fisheries experience have been criticised as being rather subjective (Fraser, 1975).

Stewart (1969) identified two critical flow bands to maintain a migratory fish stock, firstly a minimum flow or 'survival' flow, and secondly 'a migratory flow band' to induce and aid salmon migration. Preservation of this range of flows in which most fish movement takes place is therefore an important consideration in setting compensation releases for fisheries. Analyses of five years of fish count data from the Rivers Lune and Leven in Cumbria, N.W. England led Stewart to suggest a survival flow of 2.41 Ml/day/metre width of river with migration commencing at flows of 7.23 Ml/day/metre width reaching a maximum at flows of 17.3 Ml/day/metre width of river. Cragg-Hine (1984) analysing data from fish counters on other North West rivers confirmed Stewart's lower range of migration flows. He presents a plot of the frequency of occurrence of water level with the number of fish moving at each water level and suggest that fish actually move at flows less than their preferred flow, but this is still in excess of the modal flow of the stream. Such analyses of fish count data relate only to the free swimming stage, and are complicated by the lack of knowledge on the downstream availability of fish. This problem has also been acknowledged by Peters et al (1973) and others working with fish counters.

Fraser (1975) provides a comprehensive review of the extensive research in Western USA and Canada to set flow requirements for fish. The most widely used of these empirical methods is that developed by Tennant (1975). In recommending flows as a percentage of the mean discharge the method is similar in approach to that of Baxter (1961). On the basis of annual flow as a suitable short term survival flow, and 30% and 60% of the average for resident salmonids during October to March and April to September respectively.

Increased recognition of the conflicting interests on important fishing rivers in USA has led to the development of complex computer simulation models for assessing 'instream flow requirements'. Numerous approaches have been developed, and Petts (1984) reports that in 1980, some eleven different methods were in use in the USA. Fraser (1975) outlines some of these earlier methods eg Oregan method in 1972. One of the most widely applied simulation models is the 'Instream Flow Incremental Method' (IFIM) developed by the Co-operative Instream Services Group of the U.S. Fish and Wildlife Service in 1976 and outlined by Wesche and Rechard (1980). The IFIM model estimates the relative amount of physical habitat available, or weighted usable area (WUA) for various life stages of fish under different flow conditions. Detailed field surveys relate fish occurrences to conditions of flow namely depth, velocity, substrate and temperature, and flow preference curves are derived for different life cycle stages.

The IFIM has been applied in several countries outside the USA, including Canada (Mathur et al., 1985), New Zealand (Scott et al., 1987), Australia (Gan & McMahon, 1990), Norway (Heggenes et al., 1990) and France (Souchon et al., 1989). The first application in the United Kingdom was undertaken on the River Blithe in Staffordshire and the River Gwash in Leicestershire/Lincolnshire (Bullock et al., 1991). For this application habitat suitability (preference) curves were derived by the Institute of Freshwater Ecology (Armitage & Ladie, 1991) and the Institute of Terrestrial Ecology (Mountford & Gomes, 1991).

The Physical Habitat Simulation (PHABSIM) software is a key component of IFIM. It is driven by field survey information, being a transect-based method in which the physical parameters are measured at each of a number of sampling points across each transect within a specified study reach.

The application of PHABSIM is not appropriate in situations where it is thought that a parameter other than physical habitat is limiting to populations of aquatic species. Water quality and temperature are examples of such parameters.

River Regulation

Most water supply and regulatory reservoirs in Britain are located in the headwaters and local effects concern chiefly resident and migratory salmonids.

In the River Tees below Cow Green Reservoir, river regulation eliminated the daily minimum flows that were less than 10 per cent of the annual mean. Regulation also caused a marked reduction in the amplitude of the daily flow maxima and of the water temperature fluctuations (Crisp, 1977). Stable environmental conditions in the River Tees below the dam led to an increase in the number of bullheads (Crisp, 1977). The population density of trout below Cow Green dam rose by only 40 per cent.

In the Afon Clywedog, sudden regulated eroded spawning gravels and reduce the recruitment success of trout. Elliott (1976), Cowx et al., (1981) observed that the washout of trout eggs from redds increased with water velocity.

Even when reservoir releases do not alter the dynamics of fish populations, angling success may be changed, often many kilometres from the point of release. Thus, North and Hickley (1977) found that large scale releases of compensation water from Llyn Clywedog and Llyn Vyrnwy reduced anglers' catches in the upper and middle Severn Valley, but increased catches further downstream. Angling success was related principally to water temperature, with the optimum temperature being 14.9°C in the lower sections and 18 to 20°C in the middle and upper sections. Flow itself only influenced angling success above a critical flow, which varied in different parts of the river: approximately 3000, 5000 and 10 000 Ml/d in the upper, middle and lower sections, respectively (North, 1980).

Inter-Basin Water Transfers

In water transfers from the Great Ouse to the River Stour, Suffolk the fish predator, zander *Stizostedion lucioperca* was able to survive passage through high pressure pipes (over 50 m head of water) and to pass through, or by-pass, an 8mm mesh screen (Guiver, 1976). In Wales, roach and dace were able to enter Llandegfedd Reservoir despite the presence of a 0.38 mm mesh over the intakes (Solomon, 1975).

Water supplies received from the Wye and Severn are eventually released as treated effluent into the river Tame, a tributary of the River Trent. The volume of treated effluent is sufficient to maintain river levels above normal. In the 1950's and 1960's the Tame contained no fish, but the quality of effluent has improved sufficiently in recent years for populations of roach, dace, bream, chub, bleak and gudgeon *Gobio gobio* (Severn Trent Water Authority, 1983).

Water Abstractions

Low flows over weirs in the River Severn have impeded the upstream migration of allis shad *Alosa alosa* and twaite shad *Alosa fallax* to their shallow, gravel spawning grounds (Claridge and Gardner, 1978; Aprahamian, 1981). Winstone et al. (1985) assessed the swimming capacities of different sizes of fish, and calculated the range of flows that stimulated fish to pass over the weirs. Similarly, Cragg-Hine (1985) described the practical use of computer simulations in determining the criteria for water abstractions that will minimise the impact on critical flow ranges for salmon and sea trout migration.

Reduced flows associated with a natural drought resulted in a loss of spawning and feeding areas in the River Lambourn, a chalk stream tributary of the River Thames(Wright and Berrie, 1987). In Candover Brook, Hampshire, the survival of brown trout was closely correlated with mean flows in April (Solomon and Paterson, 1980.) These flows, derived almost entirely from groundwater springs, varied naturally from year to year. Hence, artificial reduction in flows by direct abstraction from the chalk aquifer (Rodda et al. 1976) can result in a reduction in trout population density. Release of pumped groundwater into the Lambourn improved the habitat by removing silt and encouraging the growth of aquatic macrophytes which harbour may important fish food organisms (Wright and Berrie, 1987), In the Gussage stream, Dorset, which dries up during the summer, groundwater pumping during this season resulted in a substantial increase in the numbers of trout, minnow, and stone loach *Noemacheilus barbatulus* (Furse, 1977).

Potential Impacts

Potential impacts of river regulation and transfers on fisheries are:

- Flow effects
- Chemical effects
- Temperature effects
- Species and disease transfer

Significance of Reduced Velocity

Reduced flow has the potential to affect fish communities in several ways. First, alteration of velocity could in theory at least affect the balance of habitat favourably for different species. However, it should also be borne in mind that to a large extent, fish communities are determined by characteristics of velocity and depth, as determined by natural gradients and profile of the river channel. Thus for instance, the fast water loving species trout, grayling and minnow tend to favour the upper reaches of rivers with gradients in the order of 3-15% (Solbe 1988). Although there is considerable overlap, dace, chub and barbel tend to characterise middle reaches where there is reasonable flow and gradients in the order 1-3%. The slow water loving coarse fish species such as roach, bream, perch and pike tend to favour the deep, slow flowing lowland rivers where gradients are usually less than 1%.

Within each of these habitat types, there is however a degree of latitude over which changes in flow could modify the balance of different species. Thus for instance, young salmon show a preference for marginally deeper and faster flowing water than do young trout (Egglishaw & Shackley, 1982). It would not be unreasonable to anticipate species changes following small alterations in average depth and velocity. Chub, barbel and dace also tend to show a discrete pattern of distribution, probably linked to highly specific flow requirements. Altogether, more information is required on minimum flow requirements of these apparently sensitive middle zone species. The deep, slow flow loving communities of coarse fish species tend to exhibit have relatively low thresholds for dissolved oxygen and for these species it is probably true to say that velocity is less critical than water depth and quality.

Migration

Several studies of salmon migration throughout the UK using radio tracking and electronic fish counters are providing invaluable information on the relationship between fish migration and river flow. These studies are aimed at the development of appropriate operating rules for abstraction, setting of prescribed minimum flows and the protection of events such as spates which may be associated with migration.

River migration in salmon can be split into three identifiable phases (Milner 1990, Clarke & Purvis 1990, Hawkins et al, 1990). The first phase involves entry from saltwater into the estuary and appears to be influenced by flow and water quality of the target river. After entry from saltwater, fish tend to migrate upstream in short bursts for a period of 2-5 weeks, interrupted by stationary periods of a few days. Movement occurs predominately at night. There follows a quiescent phase which may last several months, during which the fish take up 'lies', normally in the middle to lower reaches of the river. The "spawning run" occurs in Autumn, usually in response to discrete spate flows and results in mass movement of the spawning population into the spawning headstreams.

The first and second migratory phases occur throughout the season and result in accumulation of fish in the angling reaches in the lower and middle sections of the river. Maintenance of triggering factors for these initial migrations during the early summer months is therefore essential for good angling. In small rivers or rivers with low summer flows, there is evidence that the spawning population tends to hold up in lower or tidal reaches for the most part of the season before moving upstream on the Autumn spates (Cragge-Hone 1985). The third migratory phase or "spawning run" occurs as a fairly discrete phenomenon, usually following the first major Autumn spate. This results in the entire spawning population moving from lies in the lower or middle reaches, up to the spawning headstreams. Entrance to the spawning tributaries is associated with elevated flows, although it is not clear whether fish are responding to specific flows or increases in flows (Webb & Hawkins, 1989).

It can thus be seen that the Autumn run tends to be initiated by high flows at a time of year when abstraction is unlikely to be a critical consideration. More critical perhaps in the present context are the factors that trigger the initial phases of migration from the estuary into the lower and middle reaches of the river. It is these that determine the summer distribution of the population through the middle reaches and are therefore critical to maintaining the angling status of the river as a whole.

Management of Flows for Migration

From the studies so far conducted it is apparent that river systems vary considerably with respect to critical flows necessary for salmonid migration. NRA studies on the Tywi, Fowey and Taff have shown that low discharges result in delays in the movement of salmon into the estuary from saltwater. There is as yet no generally accepted view as to which features of flow are most important in inducing fish to enter from the estuary to the river, although some studies have attempted to identify absolute thresholds. Studies on the Tywi and ADF 3369.6 Ml/d, suggests that the probability of migration from the lower tidal reaches declines as flows fall below 80% ADF. Studies on the Hampshire Avon (Frake & Solomon 1989) with ADF is 1736.6 Ml/d, show an increasing tendency for migratory salmonids to remain in lowermost non-tidal and tidal reaches as flows fall below 65% and 50% respectively of ADF. The model assumes that absolute flow levels rather than changes in flow are the most important factor. Studies on other rivers such as the Tamar (1814.4 Ml/d ADF) suggest that increase in flow rather than flow level is the important factor. On the basis of such observations, Milner (1990) and Cragge-Hine (1989) draw attention the need to protect spate events.

Minimum flow criteria for abstraction for the Lune-Wyre transfer were designed around migration and flow characteristics as observed in Lancashire rivers and on a salmon counter on the River Lune (Cragge-Hone 1989, Stewart 1969). These suggested that salmonid migration peaked at flows equivalent to 18 Ml/d per metre width of river. The Lune ADF is 2900 Ml/d (33 cumecs) with DWF 240 Mld (2.8 cumecs). An abstraction regime was implemented which permits maximum abstraction of 10% of ADF down to minimum prescribed flow of 13% ADF (365 Mld). Also, as a result of prior fish counter observations which indicated the importance of small summer spates, an additional condition was imposed to protect any small spates in the range 680 Mld to 2045 Mld (23%-71% ADF) which occur during the dry spell May to October. Subsequent examination of fish counter data has shown that fish move freely at flows in the specified range.

The above studies suggest that flows in the order 50-60% ADF are required to induce significant salmonid movement into the lower river. Where prescribed flows are reduced below that level, special provisions may be required to retain spates during the summer period. More recent work involving radio-tracking is indicating that only flows below about 1 to 2 times Q_{95} are inhibiting for migration. The differences between recommendations from different researches has serious resource implications and needs to be resolved.

Impingement of Smolts on Intake Structures

Downstream migration of smolts occurs during a discrete period, normally around April/May each year. Migration is greatly enhanced by elevated flows but evidence from several studies shows that fish will emigrate even in the absence of spates. Of perhaps greater concern in the present context is the incidence of smolts becoming trapped in poorly sited or designed water intake structures. Section 14 of the Salmon and Freshwater Fisheries Act requires that artificial channels for the purpose of water or canal undertaking, shall install an approved grating to prevent entry of migratory fish. Following concerns that the legislative provision was being largely ignored and that the screens presently in existence were of poor design, a recent study was commissioned by the NRA to assess the situation and make recommendations.

In the present context, the problem of entrapment of smolts probably represents a significant impact in certain situations, but one which can be mitigated through careful design and siting of intakes.

Water transfers can affect temperature in two ways. First, through direct mixing of water at differing temperatures and second, through indirect changes volume and corresponding in heat absorption and retention characteristics. The magnitude of temperature changes due to mixing are considered elsewhere in this report and are generally found to be in the order of 1-2°C. In extreme cases where for instance, a lowland river with mean summer temperature of 16°C were to be augmented with 50% borehole water at 10°C, a mean temperature reduction of 3°C would be anticipated. Equally, an average winter river temperature of say, 6°C would be expected to increase by 2°C in the immediate locality of borehole augmentation.

Potential benefits or disbenefits of temperature change to the fishery are dependent on individual species and their respective response to temperature. Fish metabolism approximately doubles with 10°C increase in temperature within the optimum temperature range. Growth is affected to a lesser extent due to temperature related decreases in growth efficiency. Different species exhibit differing temperature optima and there are also differences within species for growth and spawning. Salmonids tend to show spawning optima of 2-10°C and growth optima 4-14°C. Cyprinids generally tend to have higher temperature requirements, with growth optima in the range 8-26°C. Thus for some species, normal midsummer temperatures may approach or even exceed the optimum range, such that temperature reduction may be beneficial. Equally however, increases in summertime temperature in lowland rivers may benefit the warm water loving coarse fish species.

Evidence of significant changes arising from existing transfer schemes is speculative, but there have been suggestions that temperature may have been implicated in fishery changes following the Welsh Dee and Tyne Tees transfer schemes.

Water temperature in streams affected by impoundment is modified by the storage effects and changes in flow regime. At the point of release the main effects tend to be 1) reduction in diet range; 2) depression of summer temperatures; 3) elevation of winter temperatures; 4) delay of the annual temperature cycle (Brooker (1981), Edwards & Crisp (1982). Reservoirs with multiple draw-off levels can be managed to give any one of a selection of downstream temperatures (Crisp 1987).

Due to the upland location of most impoundments, rivers affected by impoundments tend to support predominately salmonid fish communities. Crisp (1989), showed that due to elevated winter temperatures immediately downstream of a regulated reservoir, both salmon and trout show approximately 25% faster development of eggs and juveniles. Evidence from reservoirs in UK indicates that temperature effects are greatly reduced within 5km of the point of release and are not detectable 20-30km downstream (Crisp 1987).

Chemical Effects

The sensitivity of fish to water quality is well researched and the levels of acceptability for a wide range of chemical parameters can be derived from toxicological studies (Alabaster and Lloyd, Mance). Certain parameters of acceptability for salmonid and cyprinid fisheries are embodied in the EC Fish Directive 78/659/EC and were based on the results of extensive toxicological research carried out in the 1970's and 1980's and collated by the FAO/EIFAC Working Parties. Essentially, the lower thresholds of acceptability for the EC Directive correspond approximately with the lowest concentrations of substances at which a measurable deleterious effects would be expected to become detectable at population level.

For example, in the case of heavy metals the lowest concentration of detectable effect tends to be in the order of 10% of the acute lethal concentration (ie, 10% of laboratory 24 LC50). Minimum dissolved oxygen requirements are given as 5 percentile values. Thus, whereas salmonids may be expected to begin to show deleterious effects if exposed occasionally to dissolved oxygen concentrations of 7mg/l, cyprinid populations may reasonably be expected to tolerate occasional exposure to concentrations as low as 5 mg/l.

For practical purposes, strategic fisheries assessment can be reasonably based on half a dozen or so key water quality parameters. The NWC water quality classification system is based on the parameters oxygen, biological oxygen demand and ammonia, primarily with respect to fisheries requirements. The NWC classification also specifies a broad minimum toxicological specification in EIFAC terms. For present purposes therefore, a decline in BMWP chemical class status would be considered a significant impact. In specific cases where other water quality criteria appear to play a significant role in determining fish populations within a BMWP class, more detailed assessment according to EIFAC criteria may appropriate.

The relative significance of an impact should also take account of degrees of localisation. For example, where water is discharged from anoxic zones in reservoirs the outfall may carry high concentrations of iron and manganese (Crisp & Edwards 1982). These elements form complexes with colloidal organic material as streamwater becomes re-oxygenated and therefore tend to settle out immediately downstream of discharge. Similar effects are apparent in the vicinity of groundwater discharges from metalliferous strata. Although there are indications that such effects may severely affect the survival of salmonid eggs over a short distance, impacts on the well being of salmonids in the river as a whole may be quite small.

Disease Transfer

Fish disease controls are presently under review in order to meet the requirements of the EC Fish Health Directive 91/67 which came into force in January 1993. This provides a framework of controls to prevent spread of fish and shellfish diseases within the single European market and from third countries. As part of this framework, Member States may seek to obtain "approved zone" status for areas free from List I and II fish diseases. Fish Introductions will then only be allowed into zones of equivalent health status.

Approved zone status is allocated on a catchment basis and since at the present time, Britain enjoys approved zone status for List I and II diseases, fish farms can export live fish freely within the EC. Inter catchment transfer schemes would become an issue in the event of an outbreak of a listed disease in one catchment, which would automatically preclude approved zone status for export from all other connected catchments.

Of the various fish diseases caused by viruses, bacteria, protozoa and parasitic crustacea that presently occur in Britain, there are some 50 or so diseases that the NRA considers to be of sufficient importance to both the recreational fisheries and fish farms, to justify special measures to prevent movement of fish from one water to another. These can be classified into four categories, according to the level of incidence at which authorization for transfer is withheld under the Section 30 of the Salmon and Freshwater Fisheries Act, 1975.

Category A is comprised of nine diseases which are notifiable to the Ministry of Agriculture under the Disease of Fish Acts, 1937 and 1983. When detected at any level, category A diseases constitute ground for immediate isolation and treatment where practical. There are 10 Category B diseases which although not covered by the above statute, are nevertheless considered by the NRA to be of sufficient health importance to prevent movement of fish into waters that the specific disease does not exist. In such cases, detection at any level would normally constitute grounds for a Section 30 refusal of a movement permit, unless the receiving water also contains the disease.

Categories C and D are more flexible but problematic in the present context, since the decision to allow movement from one water to another is not based simply on presence or absence, but on relative degree of incidence. Categories C and D include 19 diseases for which fish movement is restricted if the disease is found to be present in a donor fish population at a specified level of infection. Criteria for acceptability range from the disease being readily noticeable in the case of category C, to causing severe debilitation in the case of category D diseases.

In the present context, thresholds of significance with regard to water transfer will depend on mere presence or absence in some cases. In others however, the relative disease status of a particular catchment will influence the impact acceptability of a water transfer. Because Category A diseases are covered by Statute, any risk of introduction from an infected donor water would automatically rank as highly significant impact. Restrictive actions for disease categories B, C and D however are presently based on NRA policy alone. These therefore offer scope for some flexibility in policy direction, subject to a thorough assessment of the relative economic importance of individual diseases and their respective levels of risk.

4. Summary

The key findings of this review are:

- Interbasin transfers are common throughout the world and have been implemented on a scale far greater than anything proposed in the UK.

- The key issues identified in the literature relate to: scale (larger scale = higher risk); appropriateness (alternative strategies which obviate the need for transfers must be considered); integration (the quality and quantity implications of all projects must be assessed in an integrated way).

- Both the high flow, medium flow, and low flow regimes play important roles for different elements of the aquatic environment.

- The high flow regime is important for "flushing" silts and sediments through the river system and into estuaries. High flows are important triggers for migratory fish and influence the extent of saline intrusion up a tidal river.

- The medium flow regime defines the "climate" to which the aquatic environment is adapted. Significant changes, particularly to the seasonality and variability of flows may cause unexpected changes to the aquatic ecosystem.

- The low flow regime is crucial, both in maintaining a survival flow for depth sensitive organisms such as fish, and for maintaining adequate dilution of effluents influencing water quality.

- Despite a recent growth in research, the complex interactions between flow regimes and aquatic ecology are poorly understood. The habitat preference curves used in the Instream Flow Incremental Methodology are starting to provide a rational basis for setting minimum environmentally acceptable flows, but the methodology has a long way to go before seasonal flow changes, water quality and aquatic ecology changes can be fully correlated and assessed.

- Provided a water resources scheme is operated so as to maintain a quantity and quality regime which is set with reference to natural conditions, then a healthy aquatic environment can be maintained. The key yardstick for acceptable changes to existing flow regimes appears to be to maintain the existing natural seasonality, variability, frequency of low flows and timing of spates.

- There is no generally recognised method for setting minimum "hands off" prescribed flows in rivers or minimum residual flows to estuaries. However, given that most discharge consents are made with reference to an existing low flow statistic, usually Q_{95}, then a prescribed flow above this value seems sensible. There is still controversy about appropriate mrf for estuaries to protect salmonid migration. Proposals range from 1 to 2 times Q_{95} up to 50% of mean flow.

- Given the complexities of predicting the changes to an entire aquatic ecosystem, a pragmatic approach is to maintain acceptable conditions for a sensitive target indicator species whose requirements are well understood. This is usually taken to be salmonid fish or flowing water cyprinids. The philosophy is that the presence of these species is an indicator of a healthy aquatic environment.

- There are inherent risks in transferring large quantities of water into adjacent catchments, which relate to: biological integrity; subtle chemical alterations; transfer of pathogens and diseases; transfer of predatory species; "fingerprinting" confusion for migratory salmonids. Particular risks are associated with transfers from the downstream ends of large lowland rivers into the upstream end of upland or middle order reaches, due to disruption of the nutrient cycle.

- The similarity between the donor and recipient stream of an interbasin transfer is a vital factor in determining its ecological effect.

- Biota are highly sensitive to changes in:

    - Water quality;
    - Hydrology;
    - Substrate.

  These are all influenced as a result of interbasin transfers.

- As a result of the transfer of biota between catchments and rivers, and the factors above, the ecological integrity of many rivers influenced by transfers is under threat.

- The scale of impact of a scheme is likely to reduce downstream and is unlikely to have any ecological effects once the catchment area of the impoundment is less than 35 per cent of the total drainage area.

- The magnitude and frequency of discharges into recipient streams may have serious implications for small streams.

- Further research is needed into interbasin transfers within the U.K. to identify the specific ecological effects.

- For fisheries, the key factors affecting populations are: changes in velocity; loss of spates/freshets; changes in habitats; changes in temperature regimes downstream of reservoirs; quality changes; introduction of new species or disease risk. All these factors require site specific data.

APPENDIX C

Experience from Existing UK Schemes

NRA NATIONAL WATER RESOURCES STRATEGY

ENVIRONMENTAL ASSESSMENT OF STRATEGIC OPTIONS

APPENDIX C

EXPERIENCE FROM EXISTING UK SCHEMES

CONTENTS

1. Introduction

There is already significant experience of major river regulation, augmentation and transfer schemes in the UK. The perceived and measured actual impacts of these schemes can provide valuable information on the range and severity of impacts under UK conditions. Experience of operating such schemes over several years also identifies opportunities for mitigation of impacts and environmental enhancement.

The construction and operation of water transfer schemes have wide environmental implications, but the principal potential impacts concern the ecology and biological integrity of the donor and recipient river systems. Although there has been a marked increase in the last decade in theoretical literature concerned with the ecological effects of river regulation (e.g. Hellawell, 1988; Boon, 1988; Mann, 1988; Gore and Petts, 1989) and river impoundments (e.g. Petts, 1984; Sherrard and Erskine, 1991), there is little hard evidence of the effects of changes in flow on biota and ecosystem functioning. The relationships between river flows, groundwater levels, wetland habitats and aquatic ecology are highly complex, and population responses to flow alterations remain difficult to predict. There have, moreover, been few studies of the specific effects of catchment transfers, and no environmental audits of transfer schemes have been carried out in the UK.

The literature review in Appendix B summarises the state of knowledge concerning theoretical and measured impacts of river regulation and inter-basin transfer from around the world. The range of environmentally damaging impacts which *could* occur is vast. But at the level of strategic assessment undertaken in this Study, there is a need to focus on those key potential impacts which have a real risk of occurring by examining the experience of existing UK schemes. These key issues can then be used as a first screening of options prior to detailed EIA.

2. Evidence from NRA Regions

The NRA identified 29 schemes covering all of the 9 regions, where there had been a significant impact on the flow regime. A summary of the 29 schemes is presented in Table 1. The majority (21) are river regulation schemes, 6 involve groundwater augmentation, and 4 involve transfers of raw water (note that 3 are multi-component schemes). As part of the present study, The regional water resources managers were requested to prepare brief summary sheets describing the measured and perceived impacts of each scheme.

The summary sheets sent in by the NRA Regions are included in Appendix F. Table 2 summarises the important environmental impacts identified for existing UK schemes. It is worth noting that very little post-scheme evaluation has been done, even in the regions with major transfer schemes such as Anglian.

TABLE 1: SCHEDULE OF SOURCES FROM WHICH SIGNIFICANT TRANSFER/REGULATION RELEASES ARE MADE
(i.e. Significant Impact on Natural Low Flow Regimes)

No	Source	Region	Scheme Type *	Date of Implementation	Description
1	Kielder	N/Y	R/T	1982	The Kielder Reservoir regulates the rivers North Tyne and Tyne. The yield is 900 Mld with a compensation flow of 114 Mld. In addition, water is transferred from the river Tyne at riding Mill southwards to the river Wear at Frosterly and river Tees at Egglestone via a 33km long tunnel with a capacity of 300 Mld for the Wear and 270 Mld for the Tees. This tunnel is mainly used to regulate the Wear to a minimum maintained flow of $2m^3/s$ during dry summers.
2	Cow Green	N/Y	R	1971	Cow Green Reservoir regulates the river Tees and supports the abstractions at Broken Scar and Blackwell. Compensation release 38.6 Mld. Scheme results in MMF rising from 45.5 Mld to 127.3 Mld.
3	Lune/Balderhead	N/Y	R	1965	Lune and Balder reservoirs on two tributaries of the river Tees and have two objectives: partly increase the direct supply yield and partly support an increased abstraction from the Tees at Broken Scar. Regulation is generally in wet autumns or springs when there is surplus capacity in the Lune/Balder and insufficient water in Cow Green Reservoir. The only other use of the scheme is when there is insufficient time to release from Cow Green to the abstraction points.
4	Vyrnwy	ST	R	1891	Vyrnwy reservoir is designed to supply Liverpool but also forms a part of the River Severn Wales Resources/Supply System together with the Shropshire Groundwater & Clywedog Reservoir schemes. Typical regulation release including compensation of 45 Mld is 80 Mld via River Vyrnwy into the River Severn river regulation during drought periods for 80 to 120 days.

No	Source	Region	Scheme Type *	Date of Implementation	Description
5	Clywedog	ST	R	1967	Clywedog Reservoir is used to augment the flows in the River Severn (along with Shropshire groundwater and Vyrnwy Reservoir schemes). Average flow in the Severn at Bewdley for 5 consecutive days maintained at not less than 850 Mld subject to maximum reservoir release of 500 Mld.
6	Carsington	ST	R/T	1992	Carsington Reservoir forms part of Severn Trent's supply strategy. Carsington is a pumped storage reservoir on Scour Brook, a tributary of the River Dove. Apart from a small natural catchment, the inflow is pumped from the River at times of high flow. Water stored in the reservoir can then be returned to the River Derwent to support abstractions or transferred to Ogston Reservoir.
7	Shropshire groundwater augmentation	ST	R	Phase I 1984 Phase II 1992	Scheme comprising 8 phases to augment flows in the River Severn during drought periods. The Severn is primarily augmented during dry periods by releases from Clywedog Reservoir, however, in drought periods water is pumped from groundwater. Total gross yield 330 Mld when completed. Gross yield of phases I and II is 105 Mld.
8	Elan Valley	W	R	Unknown	Elan Valley reservoirs consist of Claerwen, Dol-y-Mynach, Craig Goch or Pen-y-Garreg, and Caban Coch. Compensation releases of 68 Mld are maintained from Caban Coch but no compensation releases are made from the other dams upstream. Regulation releases are made to augment the flow in the River Wye to maintain 1210 Mld at Redbrook. The maximum releases from the Elan Valley reservoirs is 232 Mld (68 Mld compensation and 164 Mld augmentation) or 204 Mld depending on the storage situation. Caban Coch is used for hydro-power.
9	River Usk reservoir	W	R	19th Century to 1980s	Complex conjunctive use scheme involving the regulation of the River Usk using Usk Reservoir for direct supply to support downstream abstraction. The reservoir is used to maintain a minimum flow of 227 Mld downstream of the abstraction point. Also below a prescribed flow the reservoir used on a "put and take" basis to match the abstraction. Operating rules of this scheme still subject of discussion between Welsh Water and the NRA.

No	Source	Region	Scheme Type *	Date of Implementation	Description
10	Llyn Brianne	W	R	Unknown	Llyn Brianne Reservoir used to regulate the River Tywi to support down stream abstractions at Manorafon and Nantgaredig. The reservoir provides a continuous compensation flow of not less than 68.19 Mld. The residual flow at Nantgaredig is not allowed to fall below 136.38 Mld. The abstractions at Manorafon and Nantgaredig cannot exceed the quantity released from Llyn Brianne Reservoir in the previous 24 hours when the natural flow is 681.9 Mld or less at Nantgaredig and/or 377.3 Mld or less at Manorafon.
11	Llys-y-Fran	W	R	Unknown	Water is transferred from Pont Hywel on the Eastern Cleddan to Prescelly Reservoir on the River Syfynwy. Natural overflow and compensation releases pass from the Prescelly Reservoir downstream to Llys-y-Fran Reservoir. Releases from Llys-y-Fran Reservoir are used to support abstraction at Canaston Bridge and maintain minimum residual flow at Canaston Weir of 68.2 Mld. In addition, Llys-y-Fran also provides a constant compensation release of not less than 13.638 Mld and Pont Hywel has a "hands-off" flow of 4.546 Mld. Llys-y-Fran is also used for hydro-power.
12	River Brenig	W	R		N/A
13	Celyn	W	R	Unknown	A series of reservoirs in the upper River Dee catchment which are used to support abstractions downstream. Reservoirs include: Llyn Celyn, Llyn Tegid, Alwen and Llyn Brenig. Compensation releases made from all these reservoirs to support fisheries; maintenance of water quality; mitigating flooding & supplying BWB. Llyn Celyn and Alwen Reservoirs are used for hydro-power.

No	Source	Region	Scheme Type *	Date of Implementation	Description
14	Lancs. Conjunctive Use	NW	R/G/T	1979	Complex conjunctive scheme involving river regulation, transfers and groundwater. Water transferred from the River Lune up to a maximum of 280 Mld to the River Wyre via 6.848km of 2.6m diameter pipeline, 5.2km of 1.8m diameter pipeline, and 0.7km of 3m diameter tunnel, to support abstractions on the River Wyre. The scheme also includes 41 boreholes to provide a maximum of 195 Mld into direct supply and use of existing upland reservoirs at Stocks and Barnacre.
15	Alre groundwater	S	G	1982/83	This scheme is located in the upper reaches of the River Itchen to the east of Alresford. Consists of 4 boreholes connected by pipeline to two discharge points on the River Alre. The boreholes have combined design yield of 56 Mld with net yield approximately 45% of this figure. Expected to be operated on average one year in seven when the flow at Allbrook drops below a prescribed amount. Scheme has been tested in 1989 and on a number of occasions but is it not yet officially licensed.
16	Itchen groundwater	S	G	1976	Scheme consisting of six deep boreholes in three pairs drilled into the chalk at Axford, Bradley and Preston to support downstream abstractions at Gaters Mill on the outskirts of Southampton. These sites are about 3 to 4km upstream of the perennial head of the Candover Stream, a tributary in the Upper Itchen catchment. Each borehole has a design yield of 27 Mld. The boreholes are connected by pipeline to two river discharge points at Northington Village. The scheme is operated when flow in the River Itchen at Allbrook gauging station falls below the prescribed flow. This varies throughout the year, with a minimum of 239 Mld in the summer months. The flow in the Candover Stream is monitored at Borough Bridge gauging station. The Q_{95} of the Itchen at Allbrook is 254 Mld.

No	Source	Region	Scheme Type *	Date of Implementation	Description
17	Ardingly	S	R	1978	Ardingly Reservoir forms the main part of this scheme which provides augmentation releases to support downstream abstractions at Ardingly and Barcombe, via Shell Brook, under low flow conditions. During high flows the reservoir is filled from the Ouse. A minimum flow of 18.2 Mld is maintained at Barcombe. In addition, augmentation releases are made when flow in Shell Brook drops below 0.9 Mld and/or flow in the River Ouse drops below 13.6 Mld. The Q_{95} at Barcombe is 32 Mld.
18	Bewl reservoir	S	R	1968	Bewl Reservoir on the upper reaches of the River Teise, a tributary of the River Medway, forms the main part of this scheme. The scheme is designed to provide additional water for direct public supply and support downstream abstractions, and regulate the river under low flow conditions. Under high flow conditions in the River Teise, normally in winter, water is transferred using Smallbridge Pumping Station via a pipeline to Bewl Reservoir. When the flow drops below a prescribed rate at Teston Weir on the River Medway, water is released from Bewl into the Rivers Bewl/Teise/Medway to augment the river flow. Maximum augmentation is 65 Mld. The Q_{95} at Teston is 125 Mld.
19	Wimbleball	SW	R	1978	Wimbleball Reservoir on the River Haddeo in the upper Exe catchment is used for direct supply via a pipeline to Maundown. In low flow periods releases are made from Wimbleball to maintain 273 Mld at Thorverton gauging station. Compensation flows 9.1 Mld.

No	Source	Region	Scheme Type *	Date of Implementation	Description
20	Roadford	SW	R	1989	Roadford Reservoir forms the centre piece of a complex river regulation scheme. The scheme operates in conjunction with abstractions from the rivers Tamar, Tavy, Dart, Torridge and Taw, as well as Burrafor and Meldon reservoirs. During wet periods water is abstracted directly from rivers and smaller reservoirs. During dry periods Roadford Reservoir water is transferred outside the catchment by pipeline north to Torrington and released directly into the river Tamar to support public supply abstractions. In addition, water is transferred from the Tamar to Littlehempston on the river Dart.
21	Colliford	SW	R	1984	Colliford Lake is used for direct supply to De Lank and St Cleer WTWs and for augmentation of the St Neots River and the River Fowey to support abstraction at Restormel. Colliford Lake is used in conjunction with Silybeck Reservoir. Frequency of operation dependant on prescribed flows in the rivers Fowey and De Lank, and the Withey Brook.
22	Ely-Ouse/Essex	A	T/G	1970s?	This scheme involves the transfer of up to 228 Mld from the Ely Ouse to the River Stour via a 20km long 2.5m diameter tunnel to Kennet Pumping Station and a 14.3km long 1.83m diameter pipe to Kirtling Green outfall. Water is them pumped from the River Stour at Wixoe through a pipeline 1.68m diameter 6.3km into a storage tank and gravity fed into the River Pant. Water is then transferred downstream on the River Pant at Langford to Hanningfield Reservoir. Water is also transferred from the River Stour at Stratford St Mary to Abberton Reservoir and from the River Colne to Ardleigh Reservoir.
23	Grafham	A	R		N/A

No	Source	Region	Scheme Type *	Date of Implementation	Description
24	Trent/Witham/ Ancholme	A	T	?	Abstraction from the River Ancholme supported in low flow periods by pumped transfers from the Lower River Witham via a 1200mm diameter pipeline. The River Witham is in turn supported in low flow periods by pumping from River Trent into Fossdyke Canal. River Ancholme regulated up to a flow of 118 Mld (79.5 Mld public supply and 38.5 Mld to maintain: existing demands; navigation; fishery; and environmental considerations).
25	Rutland/Grafham	A	R		N/A
26	Great Ouse (& others) groundwater augmentation	A	G	1994	Groundwater scheme with boreholes in the chalk aquifer for public supply and river flow augmentation under low flow conditions. River augmentations by 6 boreholes and supply pipelines.
27	Great Eau/Louth Navigation/Water Beck	A	R/T	1970	Transfers from River Great Eau via 36 inch diameter pipeline to Louth Navigation and off take to Covenham Reservoir. The water levels in the Louth Navigation and Waith Beck are controlled by raising or lowering weir gates at Tetney Lock. Scheme supplies 72.7 Mld to consumers on the Humber Estuary.
28	W. Berkshire groundwater augmentation	T	G	1976	32 Boreholes grouped into 7 wellfields joined by 89km of pipeline to 4 major and 23 minor outfalls on the following rivers in west Berkshire: river Pang, river Lambourn, river Enborne, Foudry Brook, river Loddon. Maximum reliable yield 130 Mld with about 85 Mld after prolonged pumping.
29	Wylye groundwater augmentation	Wx	G	1975	Groundwater scheme comprising 7 boreholes to provide river compensation flows in the upper Wylye catchment. Discharge is via short pipelines to the river.

No	Source	Region	Scheme Type *	Date of Implementation	Description
30	Malmesbury/Avon River groundwater augmentation	Wx	G	1981	Groundwater scheme comprising 8 boreholes to provide river compensation flows in the upper Avon catchment. Approximate augmentation of 8 Mld.

Key: R - River Regulation
G - Groundwater augmentation
T - Transfer
N/A - Not available

TABLE 2: SUMMARY OF IMPACTS OF EXISTING UK SCHEMES

REGULATION BY IMPOUNDMENT

POSITIVE

Geomorphology	Water Quality	Fisheries	Aquatic Ecology	Terrestrial Ecology	Recreation/Navigation
	Capability to release water to purge system in cases of pollution incident Welsh Llys-y-Fran Possible improvement at times of low flow due to reservoir releases Southern River Medways Scheme	Increase in fine organic material increases input to food chain Welsh: Llys-y-Fran Increase wetted width provides juvenile habitat downstream during dry summers and increase movement of adult returning fish Welsh: Llys-y-Fran Welsh: River Tywi SW Wimbleball Reservoir Creation of high quality put and take fishery Welsh River Dee Regulation Temperature change benefits dace Welsh: River Dee Regulation Small capacity for fisheries releases (freshets) depend on operational constraints	General enhancement of flows can be beneficial SW: Roadford Reservoir	Reservoir forms valuable wetland habitat for wildfowl in areas deficient of such habitat Welsh: Llys-y-Fran Scheme	Controlled releases benefits canoeing Welsh: River Dee Reservoir provides recreational opportunities for watersports SW Wimbleball Reservoir Severn-Trent: Clywedog Reservoir Vyrnwy Reservoir Small amenity benefit due to releases Southern River Medway Scheme (benefits for the Bewl and Tuse)

NEGATIVE

Geomorphology	Water Quality	Fisheries	Aquatic Ecology	Terrestrial Ecology	Recreation/Navigation
	pH stratification due to thermal stratification. Acidification of surface water, low pH, low diss calcium, high Al. Moderate temperature regime Northumbria and Yorkshire Kielder and River North Tyne Severn-Trent: Carsington Reservoir Welsh: River Dee Welsh: Elan Reservoir Welsh: Usk Reservoir Welsh: Tywi Scheme Severn-Trent: Clywedog Reservoir Sedimentation of iron and manganese rich precipitates in/on sediment immediately downstream of reservoir Welsh: Tywi Scheme - impact for 3km d/s Precipitation of humic material d/s due to inadequate removal of lake floor soil				

NEGATIVE

Geomorphology	Water Quality	Fisheries	Aquatic Ecology	Terrestrial Ecology	Recreation/Navigation
Increased scour below Dam Compaction of gravels Northumbria and Yorkshire Kielder Reservoir	Increased phosphate and nitrate inputs from ag. sources around reservoir becomes meso/eutrophic Llys-y-Fran River Regulation Scheme South West Colliford Reservoir Increased organic loading resulting from algal blooms (see above) and fish rearing Welsh: Llys-y-Fran Decrease in DO cons of sediments immediately downstream of dam due to settlements of detritus from fish farms and algae Welsh: Llys-y-Fran Implications for effluent dilution and long term quality objectives Welsh: Llys-y-Fran Scheme Temperature decrease due to release of colder water from bottom of thermally structified reservoir in summer months. Delays in outset of temperature rise in spring Increased temperature in spring Welsh Tywi Scheme (R) up to 15c difference between epilimnion and hypolimnion, effects for less than 36km Welsh: Usk Reservoir				

NO IMPACTS

Geomorphology	Water Quality	Fisheries	Aquatic Ecology	Terrestrial Ecology	Recreation/Navigation
Welsh Elan and Usk Northumbria and Yorkshire Cow Green regulation					

POSITIVE

Geomorphology	Water Quality	Fisheries	Aquatic Ecology	Terrestrial Ecology	Recreation/Navigation
		Additional opportunities for angling Anglian Trent-Witham-Ancholm Scheme Enhancement of flows and possible encouragement of fish to penetrate further into the system earlier in the year SW Exe/Tamar transfer via River Mole	Opportunities to flush blanket weed during dry periods Anglian Improvements through maintenance of flows through drought Anglian	01	Controlled releases for leisure activities especially canoeing Anglian

NEGATIVE

Geomorphology	Water Quality	Fisheries	Aquatic Ecology	Terrestrial Ecology	Recreation/Navigation
Increased erosion necessitating channel improvement works Transfer of water with potentially more silt than recovering water course Anglian: Trent-Witham-Ancholme Schemes Reduced channel capacity at times of significant weed growth leading to flooding	Algal rich water to low algae river Anglian: Ely-Ouse-Essex Scheme Rapid changes in chemistry and/or temperature particularly if augmented by ground or surface water Anglian Transfer of disease (sugar beet rhizomonia, potato eelworm) Anglian: (perceived) DO sag and anaerobic conditions resulting from water trapped in a system when no transfer occurring Setting of discharges becomes a problem what happens if do and water is not available Anglian	Effects due to angling by high sustained flows Anglian-Ely-Ouse-Essex Schemes Effects on spawning by high pumping rates (esp. March-June) during cyprinid spawning season Anglian Clear/turbid conditions affect fish behaviour and angling Anglian Standing in supported tributaries when transfer switched off Anglian Transfer of alien eggs/larvae fry etc eg zander Anglian N. West Lancashire Conjunctive use scheme introduction of dace from Lane to Wyre Significant effects on fish populations Anglian R. Burn Fluctuating water levels affecting angling Anglian Requirement for fish pass and training works at abstraction point weir NW Lancashire Conjunctive Use Scheme			

POSITIVE

Geomorphology	Water Quality	Fisheries	Aquatic Ecology	Terrestrial Ecology	Recreation/Navigation
	Better flows, increased dilution: Anglian's Lodes-Grantes Scheme South W. Malmersby Avon River Regulation Scheme Better quality (in general) Thames: West Berkshire groundwater scheme				Amenity consolidated SW Upper Wyelye River Regulation Scheme Enhanced low flows Thames: West Berkshire Groundwater Schemes

NEGATIVE

Geomorphology	Water Quality	Fisheries	Aquatic Ecology	Terrestrial Ecology	Recreation/Navigation
Anglian	Low dissolved water Severn Trent Shropshire Groundwater Scheme Lower temperature Shropshire Groundwater Scheme Increased iron/manganese Construction impacts	Reduced temperature effects fish growth and reproduction Severn Trent Groundwater Scheme Flow charges reduced salmon migration to estuary and upstream Severn-Trent: Shropshire Groundwater Scheme Angling affected by high turned flows Effects of high pumping sites during cyprinid spawning stream Fish attracted into supported tributaries and subsequent stranding when pump stops Nitrogen gas giving fish the bends	Loss of macro invertebrates SW Upper Wyelye River Regulation Scheme		

NO IMPACTS

Geomorphology	Water Quality	Fisheries	Aquatic Ecology	Terrestrial Ecology	Recreation/Navigation
Southern Itchen Groundwater	Southern Itchen Groundwater	SW: Malmersby Groundwater Scheme SW: Upper Wyelye River Regulation Scheme			Thames: West Berkshire Groundwater Scheme SW Malmersby Avon River Regulation Scheme

3. Impacts of Selected Existing UK Schemes.

For the majority of schemes, inadequate information exists to make a balanced assessment of the key environmental implications. But for six schemes, covering the range of components which are assessed in detail in the National Water Resources Strategy, there is sufficient information to identify the key impacts.

Although there are currently five river transfer systems in operation in the country, only two of these, the Ely Ouse to Essex and the Kielder reservoir scheme, have sufficient environmental monitoring data to justify their inclusion. The remaining schemes in the analysis involve groundwater abstraction and reservoir storage for river regulation to support abstraction, both of which are potential components of an inter-regional transfer system. The six projects illustrate the range of ecological impacts discussed in the theoretical literature, and provide an indication of the significance of the key impacts and measures for their mitigation.

3.1 Ely Ouse to Essex Transfer Scheme

Concern that development in the South Essex region would lead to a shortfall in water supplies in the 1970's led to the promotion of a scheme to transfer surplus water from the Ely Ouse to the headwaters of the Essex rivers, under the Ely Ouse-Essex Water Act of 1968. River flow which would otherwise discharge directly through King's Llyn to the Wash is impounded in the Cut Off Channel by sluices at Denver, and flows in a reverse direction to be drawn off into a 20km concrete lined tunnel at Blackdyke. Water is then pumped through a 14km long pipeline to discharge to the headwaters of the River Stour. Part of the additional flow is drawn off downstream and pumped over further watersheds to the Rivers Colne and Blackwater. The transferred water is ultimately stored in two surface reservoirs, both of which had under-utilised capacity prior to the implementation of the scheme. The total transfer distances from Denver to the Abberton and Hanningfield Reservoirs through aqueducts and upgraded river channels are 141km and 148km respectively. For about two-thirds of this length use is made of existing watercourses.

The large additional flows generated by the transfer scheme have created very significant environmental impacts on the River Stour and Blackwater. Some 16km of each river channel below the outfalls have been 'improved' to accept the increased flows by widening and deepening certain reaches, and enlarging waterways through bridges and mills. In addition, ten new automatic control gates were constructed on the Stour, and one on the Blackwater, despite which there is evidence of erosion and scour around the outside of bends and in parts of the river beds (Carling, 1988). Periods of high sustained flow occur in the summer transfer months, when natural flows would be at a minimum, which may effectively prevent angling and river maintenance work from taking place. At other times, flow rates and water levels fluctuate rapidly, in association with operational changes in the rate of transfer and testing of the pump system. Although the operation of the control structures is designed to reduce the impact of variations in water level, appropriate gate openings cannot always be ensured during periods of rapid and frequent flow changes. Spatial variations in rainfall across the region, and the unpredictability of summer thunderstorms, have also created local flooding problems due to the coincidence of heavy rainfall and high pumping rates.

The principal impact on water quality is the transfer of the algal rich waters (especially *Stephanodiscus*) of the Ely Ouse to the Essex rivers headwaters, where algae levels are naturally low. This produces brown discolouration and turbid water conditions. Nutrient concentrations are also lower in the receiving watercourses than in the imported flow. Under severe drought conditions the scheme enables groundwater from the chalk outcrop in the eastern part of the Great Ouse basin to augment the transferred flows, which introduces clear water with a different chemical composition and lower temperature into the system. When the scheme is not in operation, water trapped in the pipeline system rapidly becomes deoxygenated, and oxygen sag and anaerobic conditions may result during the initial period of subsequent transfer. This is mitigated to an extent by periodic flushing releases when regulation is not required (Jackson and Bailey, 1978). The scheme provides a potential for organic pollution or pesticide contaminated water to be transferred into the receiving rivers, and MAFF have expressed concern about the possibility of transferring sugar beet rhizomania from beet factory effluents discharged to the Ely Ouse. Guiver (1976) reported a serious incident of pollution in the River Stour caused by the transfer of herbicide accidentally released into the Ouse. On the other hand, contamination from a discharge of liquid ammonia in the same river was satisfactorily treated by diverting extra water through the transfer to flush out the chemical. Similarly, short term high rate transfers are used to control the accumulation of blanket weed as part of the regular channel maintenance programme.

Scouring and bank erosion in the headwaters of the recipient rivers (Roy and Messier, 1989), and the reduction in light intensity arising from discolouration due to algal seeding, have led to macrophyte loss and assumed consequential damage to the aquatic ecosystem, particularly to invertebrate communities (Wright et al., 1992). Boon (1976) found that populations of *Gammarus* were markedly reduced following an increase in flow caused by an experimental release of Ely Ouse water into the River Colne at a time of heavy rainfall. However, details of the ecological impacts, particularly the responses of invertebrates to chemical quality changes, have not been documented to date. High transfer rates have a direct impact on the ability of cyprinid fish to spawn successfully, since the main transfers coincide with the March to June spawning season (Cowx et al, 1984). Rapid changes from clear to turbid water undoubtedly influence fish behaviour, although the impact on population levels has not been quantifiable from routine three year fishery survey programmes. There is considerable concern about the possible transfer of alien organisms from the Ouse, which may alter species composition or cause subtle changes in the genetic constitution of species groups in the recipient waters (Boon, 1988). Davies et al. (1992) discuss the potential adverse impacts arising from the inter-catchment transfer of macroinvertebrate species. Predator-prey relationships are also influenced by such transfers; the fish predator, zander *Stizostedion lucioperca,* formerly absent from the Essex rivers, is now resident in the River Stour (Guiver, 1976). Impacts on fish have also arisen as a result of the intermittent cessation of flow support to minor tributaries, which has caused occasional minor fish kills.

The impacts on the amenity interests of the receiving rivers are variable. During steady summer releases navigation is improved, but high velocities and fluctuating water levels are detrimental to river craft. Controlled releases are beneficial for canoeing, but rapid level changes pose a risk to children enjoying water based activities. Temporary shutdowns of the pumping system have led to the drying out of the upper reaches of the River Stour (Kirtling Brook) causing a smell nuisance, and allegedly impacted on the nesting success of ducks and kingfishers.

The potential impacts of the abstraction on the Ely Ouse below Denver are to a large extent mitigated by the imposition of minimum residual flows which are required to be passed downstream to the tidal estuary. A higher minimum flow is required over the winter period, when sugar beet processing wastes are discharged to the river. The principal reason for fixing residual flows is to maintain acceptable oxygen conditions in the estuary, but other objectives include the need to reduce siltation in the tidal reaches, to dilute discharges from the King's Llyn sewage treatment works, and to limit incursion of saline water by preserving a fresh water flow to the Wash (NRA 1993).

3.2 Kielder Regulation and Transfer Scheme

The main purpose of the Kielder Reservoir Scheme was to guarantee supplies to meet the anticipated large increase in the regional water demand in N.E. England for domestic and industrial purposes, particularly in the Teesside area. The reservoir, which was filled in 1982, regulates flows in the River Tyne, and the scheme allows the transfer of water by pipeline/tunnel 33km to the south, from the Tyne at Riding Mill to the River Wear at Frosterly and the River Tees at Egglestone. The predicted demand has never been realised, and the scheme now functions principally for hydro-electric power generation by regulating releases to the North Tyne. Earlier developments for regulation of the River Tees comprised the Lune/Balder Reservoirs built after the 1959 drought to support abstractions at Broken Scar near Darlington, and the Cow Green Reservoir in the upper headwaters, completed in 1971 to provide industrial supplies for Teeside.

Prior to May 1993 Kielder Reservoir made regulation releases on a daily basis for HEP generation, except during critical dry summer periods. The releases increased the flow from 114 Ml/d compensation to a peak generating discharge of 1417 Ml/d for periods of around 6 hours. The impacts of this unnatural flow regime have been highly detrimental to the river, and a new operating mode is now in force, which involves making continuous releases over three days per week at a discharge varying from 864 Ml/d to 1382 Ml/d. The transfer tunnel was used to regulate the River Wear during the dry summers from 1989 to 1992, in order to maintain the Minimum Maintained Flow (MMF) of 173 Ml/d at Chester-le-Street. During the transfer periods, water from Kielder comprised around 50% of the natural flow in the Wear at the discharge point, reducing to 30% downstream at Chester-le-Street. The lower reaches of the river carry significant quantities of treated sewage effluent, and the nutrient-rich waters promote dense weed growth which is suspected of reducing oxygen levels in the summer months (Johnson, 1988). Prior to the support from Kielder, low flows in the Wear had resulted in severe distress to fish and occasional major fish kills. Transfers to the River Tees have been infrequent, since regulation is afforded by daily releases from Cow Green and occasional releases from the Lune/Balder reservoir group.

Monitoring of the impacts of the Kielder regulation releases has shown that low flows in the North Tyne have been substantially increased. The impact on flood flows is less well defined, but it has been estimated by the NRA (Northumbrian and Yorkshire Region) that flood peaks, particularly naturally frequent events (Higgs and Petts, 1988) have been reduced by about 50% some 10km downstream of the dam. Flow velocities have been markedly increased on the rising limb of the HEP releases, whilst the releases themselves, in association with the reduction in natural flood discharges, have led to compaction of the river bed gravels. Immediately downstream of the dam there has been a reduction in salmonid populations, and the species diversity and abundance of macroinvertebrates has decreased in the same area (Boon, 1988). Haile (1987) has suggested that the impact on invertebrates may be attributable both to the fluctuating flow regime and the precipitation of organic deposits, up to 2cm in thickness and rich in iron, manganese and aluminium, on sediments downstream of the dam.

The temperature regime in the North Tyne has been moderated to the extent that the amplitude of mean monthly temperatures has been reduced by almost 6°C, with higher than natural temperatures in the winter and lower values in the summer (Crisp, 1985). Investigations into the behaviour of salmonids in the Rivers Tees and Tyne by the Freshwater Biological Association (Carling, 1979; Crisp, 1984, 1985; Cave, 1985) suggested that water temperature changes would have adverse impacts on salmon populations. In particular, fry could emerge when temperatures were too low for them to feed, and the migration of smolts to the sea could be delayed by as much as 40 days, causing them to miss the 'window' period of suitable dissolved oxygen conditions in the estuary. Whilst recent survey data have shown a reduction in salmon numbers below the dam, an increase in rod catches in the main River Tyne since the implementation of the scheme suggests that the impacts are not significant throughout the full length of the river. Results of a research programme by Newcastle University into ecological changes arising from the impoundment and releases confirm that few effects are detectable beyond 14 km downstream of the dam (Johnson, 1988).

Prior to the construction of the Cow Green reservoir, concern centred primarily on the loss of habitat for the rare alpine flora within the reservoir area, with less attention being given to potential aquatic impacts (Bisset, 1993, pers. comm.). However, post-project monitoring and detailed investigations, particularly by the Institute of Freshwater Ecology, have revealed the nature and extent of a number of significant impacts on the river system. The natural dry weather flow in the Tees at Dent Bank, assessed from pre-construction (1971) gauging data, is 48 Ml/d and this has increased to 173 Ml/d as a result of the regulation regime. Flood peaks have also been reduced dramatically, with only three of the top 63 recorded floods occurring since the construction of the dam. Armitage (1978) found that the flow stabilisation has produced an invertebrate community of low diversity but high biomass just below the dam, whereas further downstream where the substrate is more heterogeneous numbers of certain taxa have increased without displacing the previous fauna. The impacts of regulation on plant communities in the River Tees have been discussed by Holmes and Whitton (1981), and on fish populations by Crisp et al (1983). Changes in water quality have not been significant, although mean annual potassium loadings have been reduced to 60% of normal, and the seasonal temperature regime has been moderated by 1°C to 2°C (Crisp, 1977).

3.3 River Dee Regulation Scheme

The flow regime in the River Dee is currently managed by a complex system of controlled releases from three regulating reservoirs, Llyn Tegig, Llyn Celyn and Llyn Brenig, and compensation discharges from the Alwen reservoir. The general principles for regulation under the Dee and Clwyd River Authority Act 1973 are set out in the Dee General Directions (Welsh Water Authority, 1987) and the most recent description of the system is given by Lambert (1988). The scheme has the multipurpose objectives of supporting regional water supplies, mitigating flooding, maintaining flows in the Shropshire Union Canal, and safeguarding fisheries. Hydro-electric power is also generated at Llyn Celyn.

The regulation releases provide water of high quality to the main River Dee, enabling it to be maintained within Class 1A from its source to Wrexham, and Class 1B downstream to Chester Weir. Without the releases, the natural low flows in the river would be insufficient to provide adequate dilution of the treated effluents upstream of the water abstraction points. Since a major pollution incident in 1984, when an unnotified discharge of phenolic compounds resulted in some two million people receiving contaminated tap water for several days, a comprehensive monitoring and telemetric warning scheme, known as DEEPOL, has been implemented. All pollution emergencies are now detected by sophisticated monitoring procedures, and intakes temporarily shut down until the river regains its normal high quality. Computer forecasting systems enable special releases to be discharged from the reservoirs to dilute the pollution and reduce the time of travel of the contaminated water to the tideway (Weston, 1987).

The scheme is beneficial to fisheries in that special compensation releases can be made during the late autumn to improve flow conditions for migratory fish moving up the tributaries. Such discharges at this time have the additional benefit of providing enhanced seasonal flood control storage in the reservoirs (Lambert, 1988). However, faster runoff of cooler water may reduce the catchability of salmonids and coarse fish, and the reduced temperature of the regulation releases is also considered to have decreased the abundance of certain coarse fish. Hodgson (1993) attributes this to the slower growth rate of juveniles which leads to poor overwintering recruitment. Radio tracking has indicated that the steady regulated flow conditions during the summer may restrict upward movement of salmon through the tideway and reduce their activity once they enter the river. With fewer spate flows to activate movement of the fish, rod catches have fallen during the period after migration and before spawning. The decrease in large flood events has also led to increased siltation in the river, with possible damaging consequences for spawning success in salmonids and dace (Welsh Region NRA, 1993), and interstitial macroinvertebrate communities (Hellawell, 1988).

Within the Cheshire Plain the scheme involved the construction of flood embankments and other channel improvement measures. This has reduced the still-water areas within the main river, and since there are few tributaries in this section, sanctuary areas for fish are now very restricted. Smith et al. (1990) discuss the adverse impact on macroinvertebrates of the reduction in habitat diversity due to channelisation. The higher flow velocities induced by the embankments have led to scouring, which has further degraded the cyprinid habitat by restricting aquatic plant growth and microhabitats essential as food webs for fish. High releases from Llyn Celyn have also scoured the Tryweryn tributary, depleting the gravel spawning areas for salmonids and destroying the former important trout fishery in this river.

In addition to the generation of hydropower from Llyn Celyn, the regulation releases provide improved opportunities for white water canoeing in the headwater regions. The reservoirs themselves, particularly Llyn Brenig, have been developed for water-based recreation, including sailing, fishing and bird-watching. Downstream, however, riparian land owners are understandably concerned about the consequences of significant alterations to the natural flow regime. In particular, the impact of maintaining higher flows in the summer may be to increase waterlogging, and to restrict access for stock across the river. Farmers may also have to take precautionary actions such as moving their stock more frequently as a result of the rises in water level accompanying controlled releases. Nevertheless, in terms of increasing the reliability of water supplies, mitigating flooding, improving the fisheries and controlling accidental pollution discharges the scheme is generally beneficial, and illustrates many of the advantages of large-scale river management.

3.4 River Tywi Regulation Scheme

Llyn Brianne Reservoir is used to regulate the River Tywi to support downstream abstraction for water supply, in conjunction with other local sources. There is provision for compensation water and freshet releases from the reservoir for the river system, which is an important salmon and sea trout fishery for both commercial and angling interests. In recent years extensive research has been undertaken by the NRA (and former Welsh Water Authority) into the water quality impacts of the reservoir releases (1986, 1988, 1990, 1991). These are primarily due to the acidification of waters in the upper catchment, the low temperatures of water released from the bottom of the reservoir (Webb and Walling, 1993) and dissolved oxygen depletion in the Tywi estuary at certain tidal states. The general effects on instream ecology of changes in dissolved oxygen, temperature and pH, and other parameters such as ammonia and heavy metals, are reviewed by Alabaster and Lloyd (1980).

Acidification of surface waters is to a great extent attributable to afforestation in the catchment associated with the reservoir development. The reservoir also displays thermal stratification, which gives rise to pH stratification within the water column. The pH decreases with depth, so that the greatest acidity is in the hypolimnion, from which regulation releases are made. Long term monitoring indicated that increasingly low pH values, low dissolved calcium and high aluminium concentrations of the released waters were influencing the chemical composition of the main river as far downstream as Llandovery (11km), and since 1991 Llyn Brianne has been limed to mitigate this impact (NRA, 1991).

For at least 1.5km downstream of the dam the river has a severely depleted benthic macroinvertebrate community, with many flies, stoneflies, caddy flies and beetles absent or present only at low abundance. The liming of the reservoir has not resulted in any improvement of the invertebrate status. The impact of the regulation, as in the North Tyne below Kielder dam, is considered to be due to the precipitation of reservoir-derived deposits rich in iron and manganese (Hellawell, 1988), and the unnatural flow regime which increases invertebrate drift. Thermal changes are also causal, since hypolimnic releases reduce mean summer water temperatures in the river by up to 8°C, but increase temperatures in the spring. However, monitoring at a site 7.5km downstream of the dam reveals no measurable impact of the regulation releases on the aquatic ecology. Armitage et al. (1987) discuss the prediction of the response of invertebrates to river regulation, whilst Petts (1993, pers. comm.) suggests that downstream ecological impacts of impoundments are only significant where the reservoir catchment area is greater than 35% of the total basin area.

The construction of the dam caused a substantial loss of spawning and juvenile habitat for salmonids, both within the impoundment and as a result of the disruption of upstream (adult) and downstream (smolt) migration. Mitigation measures originally included a trapping and trucking scheme, but catches quickly diminished and this measure was eventually replaced with the existing smolt stocking scheme. There has been no evaluation to date of the impact of stocking on the salmonid population, but the numbers of returning adult fish continue to be lower than expected. The reduction in the magnitude and frequency of spate flows below the dam influences adult migration, and the reduced summer temperatures combined with delays in the onset of temperature rise in the spring have an impact on feeding and the emigration of parr and smolts. Shorter egg-hatching times due to increased spring temperatures also lead to the production of fry at a time when food supplies are unavailable. Moreover, the reduction in organic debris in the released waters, resulting from the efficient trapping of detritus in the reservoir, substantially decreases contributions to food chains.

It is also possible that night time abstractions from the river at Nantgaredig, upstream of the tidal head, may adversely effect the entry of fish from the estuary. Radio tracking studies indicate that under low flow conditions adult salmonids show a preference to enter the river during the hours of darkness (NRA, 1989).

Although the objectives of maintaining fisheries are fully considered in the operational release procedures, there is a strong public perception that the regulation of the Tywi is detrimental to fishing. Similarly, the Llyn Brianne reservoir, although it has no significant impact on flood levels downstream, was considered by the public to have exacerbated flooding in Carmarthen, at the head of the estuary, when the protection works for the town were overtopped in 1979. In this respect, the Tywi regulation scheme is perceived by the public as less acceptable than the River Dee Scheme in North Wales, where the impacts are generally considered to be beneficial.

The scheme also has a number of potential negative impacts on conservation interest. In 1991, 34 pairs of little ringed plovers, and 58 pairs of common sandpipers (59% and 20% of the Welsh populations respectively) bred on the gravel shoals in the lower Tywi (Tyler, 1992). There is concern today that the enhancement of flows during the spring and early summer may affect this habitat, particularly by damaging nests in the low gravel areas. There is a similar threat to kingfishers and sand martins, which nest in the river banks. The reservoir itself flooded some 20,000 ha of upland valley, including oak woodland with supported a characteristic flora and fauna. Prior to the project there was at least one pair of Red Kites nesting in the valley, and the impoundment and the associated increase in afforestation around the reservoir have undoubtedly affected the spread of this species into the area.

3.5 The West Berkshire Groundwater Scheme

The West Berkshire Groundwater Scheme was promoted in the early 1970's with the prime purpose of augmenting river flow in the Kennet and Thames to support abstractions in London. Extending over an area of almost 4000km^2 of the Berkshire Downs, the development comprises 32 boreholes and pumping stations capable of supplying groundwater from the chalk aquifer principally to the Rivers Lambourn, Pang and Kennet. An operating agreement under the Water Act 1989 states that the scheme is to be used only under drought conditions, in emergencies and for environmental protection.

The scheme was first used in full for three months at the end of the severe drought in 1976, which to date has been the longest period of operation for its prime purpose. Pumping also took place during the 1989 drought, for three weeks only, whilst individual boreholes or wellfields have been used on various occasions to support local water supplies during times of emergency. The most frequent use for one of the sites is to provide seasonal augmentation of the Letcombe Brook, a tributary of the Lambourn, which was identified by the National Rivers Authority in 1989 as one of the nationally critical rivers suffering unacceptable low flows due to excessive abstraction.

The scheme incorporates a number of measures designed to mitigate the perceived adverse impacts of the development. The envisaged risk of flooding in the small receiving rivers due to heavy summer thunderstorms at the time of augmentation was mitigated by installing a remote control facility to allow emergency shutdown during such circumstances, but to date this has not been used. Most boreholes are sited in dry valleys above intermittent flowing bourne streams and springs, and would normally operate in a drought when the watercourses would be naturally dry. It is policy not to utilise these boreholes during normal weather conditions in order not to derogate flows in the local streams and springs through increased groundwater lowering. The outfalls from the borehole pipelines have been sited below the perennial headwaters of the receiving watercourses, to avoid any potentially deleterious impact of summer flow augmentation on the ecology of the seasonally dry winterbournes. Finally, all the outfalls have been designed with baffle walls and stilling wells to minimise the risk of erosion and consequent siltation.

Regular biological and water quality monitoring, river corridor and fisheries surveys have not revealed any adverse aquatic or terrestrial ecological impacts. Nor has it been necessary to construct stream bed and bank protection works, or undertake dredging, to offset siltation and erosion. In two of the wellfields which abstract anaerobic water from the confined aquifer provision has been made to aerate the water prior to discharge to the adjacent watercourse, and thus maintain adequate dissolved oxygen levels. In general, however, the groundwater is of high chemical and bacteriological quality. The scheme is perceived by the NRA (Thames Region) to have a beneficial effect on fish populations and fauna in the receiving streams, and there may be a marginal amenity impact arising from the enhanced low flows through some rural communities.

3.6 The Shropshire Groundwater Scheme

This is a phased development designed to augment flows in the River Severn in drought years as part of the Severn Water Resources/Supply system. The River Severn is a major water resource for public supplies to the West Midlands and Bristol regions, in addition to meeting the needs of agriculture and industry. During drought periods, the flow is augmented initially by releases from the Clywedog Reservoir and, to a smaller extent, from Lake Vyrnwy. The Shropshire Groundwater Scheme is only brought into operation when storage in Clywedog falls to critical levels.

The overall scheme consists of eight stages, two of which have currently been implemented (1984 and 1992). Groundwater is pumped from the Sherwood Sandstone aquifer to the north of Telford and Shrewsbury directly to the River Severn or its tributaries. Phase I was used in 1984 and 1989, but Phase II, which was extensively test pumped in 1991/1992, has not yet been required for operational purposes.

The scheme incorporates an environmental monitoring programme designed to identify impacts and enable mitigation measures to be undertaken at an early stage. A number of adverse impacts are perceived by the NRA (Severn-Trent Region), arising principally from the chemical quality characteristics of the groundwater. Few of these have been directly observed in the receiving watercourses, however, owing to the short term nature of the augmentation. Low levels of dissolved oxygen in the pumped groundwater are of particular concern, but in practice this effect can be mitigated by the use of aerators. Increased chloride concentrations have implications for local abstractions for spray irrigation, and higher manganese and iron levels can potentially coat the stream beds, affecting both the aquatic ecology and downstream abstractions. The reduced temperature of the groundwater (10°C) may suppress fish growth and reproduction, and the release of nitrogen gas from the pumped flow has a physiological effect on fish, producing a version of the bends. Although pumping induces a decline in groundwater levels in the vicinity of the wellfields, and a consequent reduction in soil moisture levels, the impact is not considered significant in view of the generally shallow water levels at the pumping sites. The scheme, as for any river regulation operation, influences the residual flow regime to the estuary, which will have an impact on salmon migration to the estuary and upstream (North, 1980).

4. Summary

Despite the lack of firm evidence from pre/post- scheme evaluations, flow regulation has undoubtedly had an impact on river ecosystems in England and Wales, often creating gradual but significant changes over long periods of time. This is illustrated by comparing the principal regulated rivers on the one hand and rivers considered by Hellawell (1988) to be of high conservation value. Apart from a very few exceptions, notably the Usk and the Eden, sections of conservation interest are not found where the flow regime is influenced by releases from upstream storage or augmented by groundwater or inter-basin transfers. Whether there is a causal link between regulation and ecological impoverishment is a matter for debate.

In conclusion, the majority of schemes are river regulation or groundwater augmentation from within the catchment to support abstraction and maintain quality. The impacts in terms of the objectives of the schemes are therefore invariably considered as beneficial. The largest transfer scheme in operation in the UK is the Ely Ouse to River Stour transfer of up to 228 Ml/d. There are adverse effects noted for the Northumbrian Kielder and Anglian transfer schemes, especially to fisheries and aquatic ecology, but insufficient research has been done to be categoric about the severity of impacts. Some general conclusions concerning use of groundwater, interbasin transfer and reservoir impoundment based on the NRA assessments are:

Augmentation by Groundwater

The positive impacts are generally related to improvements in water quality arising from increased dilution, and to amenity benefits resulting from enhanced flows. The negative impacts are largely related to effects on fisheries from reduced temperatures and flow changes. Many schemes have yet to identify impacts.

Interbasin Transfer

Increased flows provide opportunities to flush pollutants and aid dilution, give additional opportunities for angling and increase leisure opportunities. Considerable negative impacts have been identified/perceived and include increased erosion, algal blooms, transfer of disease, transfer of pollutants, changed flow rates adversely affecting fish behaviour and spawning, and the transfer of alien fish eggs and larvae.

Regulation by Impoundment

Positive impacts are identified as general enhancement of flows benefitting aquatic ecology, formation of valuable wetland habitats in reservoirs, controlled releases increasing recreational opportunities and resulting in marginal benefits for fisheries. Negative impacts relate to increased scour below dams and compaction of gravels, changes in water quality from storage, reduced upstream fish migration, increased siltation, reduced macroinvertebrate populations, landtake affecting terrestrial ecology and conflicts between release requirements and water users. A number of schemes have no identified impacts.

APPENDIX D

Environmental Assessment of Option Components

NRA NATIONAL WATER RESOURCES STRATEGY

ENVIRONMENTAL ASSESSMENT OF STRATEGIC OPTIONS

APPENDIX D

ENVIRONMENTAL ASSESSMENT OF OPTION COMPONENTS

CONTENTS

NRA NATIONAL WATER RESOURCES STRATEGY

ENVIRONMENTAL ASSESSMENT OF STRATEGIC OPTIONS

APPENDIX D

ENVIRONMENTAL ASSESSMENT OF OPTION COMPONENTS

CONTENTS

1. EA Methodology

The basic unit of assessment has been taken to be the components which make up the water transfer scheme. The components are defined as:

River reaches	}	in which aquatic issues dominate
Canal reaches	}	
Reservoirs	}	in which general planning issues dominate
Pipelines	}	

The assessment matrices for these two groups of components differ due to the nature of the impacts. A series of assessment tables have been produced for rivers and canals; and likewise a corresponding set of tables for reservoirs and pipelines.

The potential for environmental impacts depends upon: the sensitivity of the site/receptors; the risk of significant environmental change/damage; the expected magnitude and duration of change; and the potential for mitigation. A further important factor to consider in the assessment is the opportunity for improvement or benefits associated with the scheme.

1.1 Categories and Criteria

A set of categories have been developed for each of the components. For rivers and canals aquatic issues are most important, and the categories are water resources, general character of the reach, existing water quality, fisheries status, aquatic ecology, terrestrial ecology, recreation/amenity/navigation, and general land-use/planning issues. For reservoirs and pipelines terrestrial categories are of primary importance; and the categories are general character of the landscape, agricultural land, existing archaeology and cultural heritage, terrestrial ecology, recreation and amenity opportunities, and general land-use/planning issues. Each of these categories is discussed below.

1.2 General Character/Landscape

This is particularly difficult, if not impossible, to assess accurately without a site visit. For this study the only methodology that could be used, is to consider landscape designation.

A development may be regarded as having high adverse impacts if it is located in or near a nationally designated site, i.e.,

- National Trust Properties
- National Scenic Areas

- AONB
- National Heritage Areas
- National Parks
- Heritage Coasts

A development may be regarded as having a moderate impact if the reservoir is located in/near Green Belt, Regional Park, Areas of Great Landscape Value (AGLVs) or Special Areas of Great Landscape Value, or Country Parks.

River reaches will be assessed in terms of the naturalness of the reach. Natural reaches are those with no channel works and a more-or-less natural flow regime; semi-natural reaches are those which appear to be a natural feature of the landscape but have been depth or flow regulated to some degree; artificial reaches are engineered channels for drainage or land reclamation which return some natural features or are important landscape features; highly artificial reaches are heavily engineered channels, usually through urban areas, which have lost virtually all conservation interest.

It will be assumed that a high risk of environmental impact can <u>only</u> occur in a natural or semi-natural reach.

It should be noted that:

- Some reservoirs enhance the surrounding landscape, particularly those which are flooded valley. However, bunded reservoirs such as Staines reservoir have high visual impacts.

- Visual impact will also depend on the extent of visual envelope and number of receptors affected.

1.3 Water Quality

Water quality of river reaches is defined by the NWC classification, which is used as the basis to both define sensitivity and susceptibility to risk. For the purpose of this assessment, the entire river is defined as having the highest classed reach within the river section under consideration. A high risk will be assumed whenever water of lower NWC Class is transferred into a watercourse with a higher classification.

Any water quality parameter identified in the scheme-specific Environmental Assessment as being problematic, with respect to statutory limits, will classify the affected components as having a high risk.

1.4 Fisheries

The principal impacts relating to fisheries are as follows:

- Flow effects
- Chemical effects
- Temperature effects
- Species and disease transfer

The significance of impact will depend on the magnitude of change and sensitivity/value of the fisheries.

Impacts which would be defined as high risk or highly significant are as follows:

- Loss of freshets/spates on migratory salmonids
- Reduction in low flow velocity on species with specific flowing water requirements, e.g., salmonids, chubb, dace and barbel
- Fall in NWC class or exceedence of threshold level for EIFAC parameter
- Transfer of category A pathogens, or transfer of category B pathogens if their incidence in the donor river is considered damaging
- Transfer of species

Impacts which would be considered moderate risk are as follows:

- Increased duration of velocities outside species preference
- Fish impingement in intakes
- Temperature changes due to mixing or reservoir releases
- Small changes to key WQ parameters (species dependent)
- Transfer of category C/D pathogens

In the present context, thresholds of significance with regard to water transfer will depend on mere presence or absence of diseases in some cases. In others, however, the relative disease status of a particular catchment will influence the acceptability of a water transfer. Category A diseases are covered by statute and therefore introduction from an infected donor water would automatically rank as highly significant. Restrictive actions for disease categories B, C and D are based on NRA policy alone. These therefore offer scope for some flexibility in policy direction.

1.5 Aquatic Ecology

Linking hydrology and ecology is a complex endeavour because of the many ways in which discharge influences biota. However, it is recognised that river management requires sound operational tools to determine the allocation of water to meet instream, riparian and flood plain needs. Until research has been advanced, assessment of aquatic impacts arising from flows and channel changes resulting from water basin transfer will remain qualitative, based on the following indices; BMWP scores; EQI; number of taxa and RIVPACS class.

For the purposes of this study a highly significant impact or high risk impact would be:

- Large differences in RIVPACS class between donor and recipient river

- Changes in flow seasonality

- Reduction in low flows < 1:10 drought

- Frequency of operation < 1:5

on stretches of high sensitivity, i.e., high BMWP scores, EQI > 1, high number of taxa.

Impacts would be considered moderate if changes were to occur in stretches where BMWP scores were moderate, EQI < 1 and the diversity of taxa was limited.

1.6 Agriculture

The assessment will be based on the MAFF Agriculture Land Classification (ALC) system, which classified land into five grades numbered one to five, with grade three divided into two sub-grades (3a and 3b).

The best and most versatile agricultural land falls into grades one and two and sub-grade 3a. Land in sub-grade 3b is of moderate quality and grades four and five are poor.

For land in grades 1, 2 and 3a and where more than 20 ha of agricultural land is lost, MAFF would be asked to comment on a scheme.

For the purposes of this study a highly significant effect would be where > 20 ha is lost of grade 1, 2 and 3a.

Impacts of moderate significance would be when a scheme impacted on < 20 ha of grade 1, 2 and 3a land, + > 20 ha of grade 3b land.

Impacts on grades of lesser quality are not defined as being significant.

It should be noted that:

- Planning Policy Guidance Notes PPG7 states:

"The increasing efficiency of agricultural procedures and changes in agricultural policy mean that retaining as much land as possible in agricultural use no longer has the same priority. However, PPG7 confirms the need to conserve the best land as long term valuable agricultural resource."

- Land of sub-grade 3b, 4 and 5 is of lesser importance except where particular agricultural practices themselves contribute to the quality of environment of the rural economy. Such land may be included in an ESA Environmentally Sensitive Area. This includes the three "Tir Cymen" areas in Wales.

Further requirements:

- Development of water resources may also impinge/sever particular farm holdings, or affect farm size and structure. This would need to be dealt with at a more detailed stage.

1.7 Archaeology and Cultural Heritage

The DoE PPG Note 16 "Archaeology and Planning" underlines the national importance of many archaeological sites and the need for their protection. Guidance on current policies and procedures concerning conservation areas and listed buildings is set out in DoE Circular 8/87.

Highly significant impacts are defined as those which affect World Heritage Sites, Scheduled Ancient Monuments and Grade I/II listed buildings. A development may also be regarded as significant if numerous "other" archaeological monuments were affected.

Moderately significant impacts are defined as those affecting a limited number of "other" archaeological monuments.

Mitigation measures such as excavation and recording may mitigate the above impacts.

1.8 Terrestrial Ecology

A highly significant impact would be one which affects international, European or nationally designated sites, i.e.,

- Ramsar sites
- Habitats listed in the European Habitats Directory
- Special Protection Areas
- National Nature Reserves
- SSSIs (Sites of Special Scientific Interest)
- Ancient woodland (this is also included because of its non-recreatability)

If a high number of county designated sites were affected, the impact may also be described as highly significant.

Loss of a population or impacts which affected the viability of protected, rare or declining species would also be considered highly significant.

Impacts of moderate significance are those which affect a very small number of county designated sites or local sites of nature conservation interest.

It should be noted that:

- Some of the above information, particularly on protected species and sites of local or county value, may not be available and would need further study at a later stage if the options were to be pursued

- Some river corridors have a high component of semi-natural habitat which, although not designated, still forms an important part of the resource base. Impacts to such stretches of river may be considered significant.

- Some habitats are more recreatable that others and need further weighting. This particularly applies to Ancient Woodland, the loss of which is unsustainable.

2. Component Assessments

The existing sensitivity of each category may be "high" (e.g., a NWC Class 1 river or a National Park providing extensive recreational opportunities) or "moderate". In general, receptors of national importance or with

statutory protection are deemed to be of high sensitivity. The "high" and "moderate" sensitivities defined for use in this assessment are given in Table 1 (for rivers/canals) and Table 2 (for reservoirs/ pipelines). Whilst these guidelines have usually been followed, expert judgement will be used to uprate or downrate the sensitivity based on knowledge of particular local circumstances.

In a similar manner, an assessment of risk has been performed. Risk is the potential for adverse change or significant impact consequent upon the water transfer scheme, and may be short term (only experienced during construction) or long term (experienced when the scheme is operational). The "high" and "moderate" risks defined for use in this assessment are given in Table 3 (for rivers/canals) and Table 4 (for reservoirs/pipelines). Expert judgement has been used to uprate or downrate the risk based on knowledge of particular local circumstances.

The complexity, particularly of aquatic and terrestrial ecological systems is such that the effects of particular impacts on the functioning of these systems is not yet fully understood. It is therefore extremely difficult to define specific thresholds above which impacts are defined as significant or unsustainable, and often assessment is largely based on professional experience and judgement. However, it is accepted that the basis for decision making should be as transparent as possible.

In the assessment of risk, it is assumed that the water transfers will occur as planned and modelled in the scheme-specific Environmental Assessments. Obviously a greater frequency of water transfer could lead to a completely different set of risks (e.g. the potential to fundamentally alter an aquatic ecosystem) which have not been considered in this assessment.

The individual assessment sheets for each separate option component are presented in the following Tables.

Table 1 - River/Canal Framework for Assigning Sensitivity

Category	Sensitivity		Benefit Potential
	High	Moderate	
Water Resources (WR)	Major PWS or industrial abstraction	Significant agricultural or industrial abstraction	Improve low flow problems
General Character/ Landscape (GC)	Semi-natural/natural Unregulated channel	Modified but not highly artificial	Potential for enhancing semi-natural and non-natural character
Water Quality (WQ)	NWC Class 1A or 1B SWQO - Water supply	NWC Class 2 SWQO - Contact sport	Bring Reach into Class Improve NWC Class 3 or 4
Fisheries (F)	Salmonids and certain species of coarse fish Commercially important fishery	Flowing water cyprinids	Improve low biomass Improve poor quality fishery
Aquatic Ecology (AE)	High BMWP scores Biological Class A High ASPT	Moderate BMWP scores Biological Class B Moderate ASPT	Improve low BMWP Improve low ASPT
Terrestrial Ecology (TE)	Presence of internationally or nationally designated site Numerous regionally or locally designated sites Presence of protected species	Presence of regionally or locally designated site	Increase habitat diversity
Recreation/ Amenity/ Navigation (RA)	Statutory navigation Contact water sports	Non-statutory navigation Visual amenity importance	Restore/Improve derelict navigation Improve perceived low flows
General Land-use and Planning Issues (PLN)	Conflict with existing land-use designations		Potential for enhancement identified in Development Plan

Table 2 - Reservoir Framework for Assigning Sensitivity

Category	Sensitivity		Benefit Potential
	High	Moderate	
General Character/ Landscape (GC)	Located in or near internationally or nationally designated area	Located in or near regionally or locally designated area	Increase and enhance landscape diversity
Water Quality (WA)	PWS Reservoir	Off-line river regulation reservoir	Improve downstream dilution
Agriculture (AGR)	Land Class 1, 2, 3a	Land Class 3b	Enhanced land access
Archaeology and Cultural Heritage (ACH)	Presence of internationally or nationally designated site/monument/ building	Presence of other archaeological artefacts/sites	Excavation and recording
Terrestrial Ecology (TE)	Presence of internationally or nationally designated sites Numerous regionally or locally designated sites Presence of protected species	Presence of regionally or locally designated sites .	Increase habitat diversity
Recreation/ Amenity (RA)	Presence of National Park or AONB	Presence of significant number of footpaths	Offer recreation potential
General Land-use and Planning Issues (PLN)	Conflict with existing land-use designations		Potential for enhancement identified in Development Plan

Table 3 - River/Canal Framework for Assessing Risk of Significant Impact

Category	High Risk		Moderate Risk		Mitigation
	Key Impact	Criteria	Key Impact	Criteria	
Water Resources (WR)	Derogation of existing abstraction rights Failure of any quality parameter for abstraction use	Reduction in low flows (-10% Q_{95} or MAM7) Transfer of lower quality water	Minor quality deterioration for agricultural abstraction	WQ parameter of concern for use	Prescribed flow Water treatment
General Character/ Landscape (GC)	Reduction of natural character	Alteration of channel	Minor local impact on semi-natural channel or flood plain	Construction works in/ adjacent to channel	Environ-mentally sensitive design
Water Quality (WQ)	Fall in NWC Class SWQO parameter above threshold level for use	Transfer of water of lower NWC Class Dilution at Q_{95} of problems determinands	Increased frequency of algal blooms Increased saline intrusion	Transfer of water of higher nutrient status	Water treatment Prescribed flow
Fisheries (F)	Loss of freshets/ spates for migratory salmonids Change in spawning grounds Changes in nursery grounds Change in river "smell" for migrating fish Reduction in low flow/velocity Fall in NWC Class or exceedence of threshold level for EIFAC parameter	Inspection of with/without annual hydrographs Reduction in Q_{95} or MAM7 no worse than 1:10 drought Flow increases beyond natural variation Similarity of donor/ recipient rivers and mass balance calcs. Flow reduction beyond natural variation	Increased duration of velocities outside species preference Fish entrapment on intakes Temperature changes due to mixing or reservoir releases	Outside natural variation of low flows Dissimilarity of temperature and WQ, dilution and frequency	Artificial freshets Spote sparing Fish screens + design of intakes Fisheries management policy Variable depth reservoir draw-off Treatment of transfer water

Category	High Risk		Moderate Risk		Mitigation
	Key Impact	Criteria	Key Impact	Criteria	
Terrestrial Ecology (TE)	Effects on internationally designated site Effects on nationally designated site Effects on regionally designated sites Effects on protected species	Permanent destruction or damage Permanent destruction or damage Cumulative damage to a number of sites Loss of population or decrease in viability of population	Effects on internationally or nationally designated site Effects on regionally or locally designated site	Temporary destruction or damage Permanent destruction or damage	Habitat creation, revegetation
Recreation/ Amenity (RA)	Effect on National Park or AONB	Impairment of aesthetic enjoyment	Footpath loss Footpath diversions of over 500m	Unmitigable or significant loss of footpaths	Creation of recreation/ amenity facilities
General Land-use and Planning Issues (PLN)	Prejudicing potential/planned land-use	Conflict with Development Plan		Partial conflict with Development Plan	Consultation and possibly compensation

Table 4 - Reservoir Framework for Assessing Risk of Significant Impact

Category	High Risk		Moderate Risk		Mitigation
	Key Impact	Criteria	Key Impact	Criteria	
General Character/ Landscape (GC)	Effect on internationally or nationally designated area	Permanent change to existing views	Effect on internationally or national designated area Effects on regionally or locally designated area	Temporary change to existing views Permanent change to existing views	Planned increase of visual diversity
Water Quality (WQ)	Significant algal problems in reservoir or risk of exceeding threshold of parameter for PWS use	Source and trophic status of stored/ transferred water	Anaerobic conditions in pipeline	Distance and frequency of operation	Treatment operational rules
Agriculture (AGR)	Significant loss of Class 1, 2 or 3a land	≥ 20 ha permanently lost	Loss of Class 1, 2 or 3a land Temporary loss of Class 1, 2 or 3a land Significant loss of Class 3b land	< 20 ha loss ≥ 20 ha loss	Compensation
Archaeology and Cultural Heritage (ARH)	Effect on international or nationally designated site/monument/ building Effect on other archaeological monuments	Destruction or damage to site/ monument/ building Destruction or damage to setting Cumulative damage to a significant number of sites	Effect on a limited number of other archaeological monuments	Destruction or damage to monument	Funded archaeological survey before development

OPTION 1: Unsupported Severn to Thames Transfer (400 Ml/d max; P.F. = 2500 Ml/d)
REACH: River Severn downstream of Deerhurst
TRANSFER: 400 Ml/d

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1B • Estuary Class B	• Disturbance during construction	• For PF = 2500 Ml/d	• Further studies required of min PF to estuary	• Appropriate PF	• None
Assessment	HIGH	MODERATE	MODERATE			N/A
FISHERIES	• Migratory Salmon route	• Disturbance during construction	• Concern that PF may be too low and reduce duration of migration period	• Recent studies suggest PF of 2500 Ml/d is too low for fisheries • Further studies required of min PF to estuary	• PF ≥ 4000 Ml/d • Fish screens • Spate sparing • Use of freshets	• None
Assessment	HIGH	MODERATE	MODERATE			N/A
AQUATIC ECOLOGY	• Low diversity d/s Deerhurst • BMWP Very low (3)	• Minimal impact due to current impoverished fauna		• More recent sampling data required as assessment made on historical data	N/A	• None
Assessment	LOW	LOW	LOW			N/A
TERRESTRIAL ECOLOGY	• 2 wetland SSSIs directly d/s of Deerhurst rely on periodic inundation	• Care needed to minimise disturbance on Coombe Hill SSSI	• Unlikely to reduce winter flooding • Depends on operation of P.S.	• Further research needed into link between SSSIs and hydrology	N/A	• None
Assessment	HIGH	LOW	LOW			N/A
RECREATION AMENITY NAVIGATION	• Navigable river - statutory navigation?			• Further studies required of effects of reduced low flows on sedimentation hence navigation	• Design of intake should not affect navigation • Appropriate PF • Careful landscaping of bunded storage	• None
Assessment	HIGH	LOW	LOW			N/A

Note: Low impacts provided prescribed flow set at appropriate level

Ref: 84.247.0/AW/3122/NRAFRAME.R02

OPTION 1: **Unsupported Severn to Thames Transfer (400 Ml/d max; P.F. = 2500 Ml/d**
REACH: **Thames & Severn Canal, Down Ampney to Buscot ***
TRANSFER: **400 Ml/d**

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	N/A			• Quality of water in canal	• Further studies required	• None
Assessment	N/A	LOW	LOW			N/A
FISHERIES	N/A			• Water quality and flow constraints on fishery	• Further studies required	• Creation of Cyprinid fishery
Assessment	N/A	LOW	MODERATE			MODERATE
AQUATIC ECOLOGY	N/A			• As fisheries	• As fisheries	• Creation of habitats
Assessment	N/A	LOW	MODERATE			MODERATE
TERRESTRIAL ECOLOGY		• Needs detailed survey	• Needs detailed survey and design	• Line of canal needs to be surveyed	• Detailed planning • Care in construction	• Opportunities for creation of new habitats
Assessment	N/A	LOW	LOW			MODERATE
RECREATION AMENITY NAVIGATION	• Canal presently infilled		N/A	• Source of water for canal when transfer not in use • Whether Severn link to be restored	• Detailed planning	• Restoration of canal, link into Thames system
Assessment	N/A	LOW	LOW			HIGH

Note: * Canal presently disused and infilled; this section would be restored under scheme.

OPTION 1: Unsupported Severn to Thames Transfer (400 Ml/d max, P.F. = 2500 Ml/d)
REACH: River Thames downstream of Buscot
TRANSFER: 400 Ml/d

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1B • Major PWS abstractions downstream	• Disturbance of suspended solids	• River 80% Severn water • Unlikely to cause class change but may be significant changes to base chemistry, heavy metals and trophic status	• More detailed WQ studies required	• High suspended solids from Severn mitigated by storage and settling	• None
Assessment	HIGH	LOW	HIGH			N/A
FISHERIES	• Designated Cyprinid fishery	• Disturbance of suspended solids	• Flow 5 x Q_{95}, seasonality changed • Habitat will essentially remain favourable for coarse fishery but could alter species/distribution	• Knowledge of present Thames fisheries • Clarification of disease transfer risks required • Risks of water chemistry of Severn to Thames fisheries	• Mixing of Severn water and Thames groundwater in gravel pits	• Improved low flows may improve fishery
Assessment	MODERATE	LOW	LOCALLY HIGH MODERATE			LOW
AQUATIC ECOLOGY	• V.High BMWP of 212 • Biological Class A • No. of taxa 40 ASPT 5.3	• Disturbance of suspended solids	• Local risks moderate to high • Regional risks low to moderate	• Unknown impacts of longer duration of medium flows on substrate and habitat • Unknown impacts of major changes to water chemistry on biota		• Potential for reduced channel maintenance due to increased low flows. • Opportunities for habitat improvements
Assessment	HIGH	LOW	LOW			LOW
TERRESTRIAL ECOLOGY	• ESA • SSSIs • Sites of County value	• Buscot is National Trust site	• Increased flows not likely to affect riparian wetland sites or river corridor	• Effects on drainage of riparian areas	• Maintain existing water levels in riparian areas	• None
Assessment	HIGH	LOW	LOW			N/A
RECREATION AMENITY NAVIGATION	• Thames navigable to Lechlade, heavy use • Landscape importance	• Buscot is National Trust site	• Increased late summer flows unlikely to alter • Velocities could affect navigation	• Changes in velocity • Frequency of operation	• Keep velocities below level suitable for navigation	•May improve navigation in Upper Thames in low flow years
Assessment	HIGH	LOW	LOW			MODERATE

Ref: 84.247.0/AW/3122/NRAFRAME.R02

OPTION 2: Craig Goch Reservoir

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION POTENTIAL	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
AGRICULTURE	• Land classification Grade 5. Very poor quality	• Although poor quality still provides valuable winter grazing in the context of the area		• Detailed evaluation of agricultural impact	• Compensation • Value of other grazing land could be improved with provision of shelter	•May improve access into the area
Assessment	LOW	LOW	LOW			LOW
COMMUNITY IMPACTS	• 3 farmsteads inundated (tenancies rather than hereditary land holdings)	• Effects on access • Noise, disturbance		• Based on historical report; detailed evaluation of holdings required	• Compensation and provision of alternative land holdings	• May improve access into the area • May bring in more visitors
Assessment	LOW	LOW	LOW			LOW
ARCHAEOLOGY AND CULTURAL HERITAGE	• No Scheduled Ancient Monuments. • 29 sites of archaeological interest. • No listed buildings	• Inundation of at least 29 sites of interest		• Detailed archaeological evaluation required	• Field survey and recording	• Detailed survey undertaken before inundation
Assessment	MODERATE	MODERATE	MODERATE			LOW
GENERAL LANDSCAPE CHARACTER	• Environmentally Sensitive Area. • Western Upland Special Landscape Area		• Depends on use of storage in operations	• Detailed landscape assessment required	• Careful landscape design for reservoir/dam	
Assessment	MODERATE	MODERATE	MODERATE			LOW
TERRESTRIAL ECOLOGY	• Nationally important SSSIs. • Proposed SPA* • Locally important hay meadows	• Possible effects on 3 SSSIs during construction and road diversion	• Risks on SSSIs	• Detailed ecological impact assessment required	• Setting of top water level • Careful landscape design	•Increased lake area not considered significant for wildlife
Assessment	HIGH	HIGH	HIGH			LOW
RECREATION/ AMENITY	• Locally important	• Numerous public footpaths will be inundated		• Detailed evaluation of recreation/amenity potential needed	• Establish new footpaths, nature trails, amenities	• Considerable recreational benefits but several other reservoirs in area
Assessment	LOW	MODERATE	LOW			MODERATE

* SPA = Special Protection Area

OPTION 2: Craig Goch Regulation of the Severn (600 Ml/d max regulation release)
REACH: River Severn, Llanidloes to Coalport
TRANSFER: 600 Ml/d

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1B	• Tunnel construction could disturb river	• Temperature regime changes • Hardness reduction • Fall in pH	• More detailed water quality studies of Upper Severn with Craig Goch regulation required	• Controlled drawoff temperature from different levels • Careful tunnel construction	
Assessment	HIGH	MODERATE	MODERATE			LOW
FISHERIES	• Second most important salmonid river in England & Wales	• Disturbance of suspended solids	• Flows 5 to 1.6 x Q_{95} seasonality changed • Significant effect on the extent of inundation of salmonid nursery areas and on substrate/channel	• Selected level drawoff from reservoir required • Detailed studies of channel configuration required	• Reproduce flow seasonality/ variability	• Increased regulation may help maintain low temperatures during droughts
Assessment	HIGH	MODERATE	LOCALLY HIGH			MODERATE
AQUATIC ECOLOGY	• High BMWPs, ASPTs Class A	• Disturbance of suspended solids	• Local risks may be significant	• Detailed study of effects of present regulation needed	• Ensure that margins seasonally, gravel habitats exposed	• None
Assessment	HIGH	MODERATE	MODERATE			MODERATE
TERRESTRIAL ECOLOGY	• No detail available	• Tunnel construction may disturb habitats	• Unlikely to be significant effects	• No information on wetland SSSIs but could be affected by increases in flow	• Dependent on site specific data	
Assessment	UNKNOWN	LOW	LOW			LOW
RECREATION AMENITY NAVIGATION	• Water sport activities	• Disturbance of suspended solids	• Could affect angling • May affects water sports	• Detailed examination of river use	• Limit on flows, velocities and levels	
Assessment	MODERATE	LOW	LOW			LOW

OPTION 2: Craig Goch Regulation of Severn (400 Ml/d max regulation release)
REACH: River Severn, Coalport to Deerhurst
TRANSFER: 400 Ml/d

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1B	• Construction of intakes will have localised impacts	• Some reduction in pH and hardness • Already regulated	• More detailed WQ studies of impact to middle Severn chemistry required		• Improved dilution in middle reaches
Assessment	HIGH	LOW	MODERATE			MODERATE
FISHERIES	• Important Salmonid & Cyprinid fishery	• Disturbance of suspended solids	• Low flow change 1.6 x Q_{95}, decreasing down-stream • Already regulated	• Effects of existing regulation to be studied • Detailed study needed	• Reproduce flow seasonality and variability	
Assessment	HIGH	LOW	MODERATE			LOW
AQUATIC ECOLOGY	• High BMWP upstream of Tewksbury	• Disturbance of suspended solids	• Already regulated, may be on threshold	• Effects of existing regulation to be studied • Detailed study needed	• Ensure that marginal seasonally dry gravel habitats exposed	
Assessment	HIGH	LOW	MODERATE			LOW
TERRESTRIAL ECOLOGY	• Detailed information not available	• Construction of intakes will have localised impacts	• Unlikely to be significant impacts	• No information on wetland SSSIs but unlikely to be affected by moderate increases in flow	• Dependent on site specific data	
Assessment	UNKNOWN	LOW	LOW			LOW
RECREATION AMENITY NAVIGATION	• Water sports	• Disturbance of suspended solids	• Unlikely to be significant impacts	• Detailed examination of river use	• Limit on flows, velocities and levels	
Assessment	MODERATE	LOW	LOW			LOW

OPTION 3: **Craig Goch Regulation of Wye and Thames Transfer (400 Ml/d max regulation release)**
REACH: **River Wye, Nannerth to Ross-on-Wye**
TRANSFER: **400 Ml/d**

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1A down to Hereford	• Construction of tunnel could disturb river	• Upper river dominated by Craig Goch water	• Previous WQ study now out of date may need updating to assess latest WQ data	• Careful control of temp. and DO through drawoff facilities	• Improve water quality in upper river where acidisation
Assessment	HIGH	MODERATE	MODERATE			LOW
FISHERIES	• Best salmonid river in England & Wales	• Disturbance of suspended solids	• Low flow increased 10 to 2 x Q_{95}, seasonality changed • Risks to spawning/nursery areas • Some risk from impact of high flow regime	• Salmonid response to flow and "smell" changes • Effects on substrate and channel characteristics	• Reproduce flow seasonality and variability	• May improve reliable drought flows and benefit fishery
Assessment	HIGH	MODERATE	HIGH			LOW
AQUATIC ECOLOGY	• SSSI • High level of naturalness	• Disturbance of suspended solids	• High local impact at top of Wye catchment	• Impacts of enlarging reservoir upon flood regime and channel processes need consideration	• As fisheries	• As fisheries
Assessment	HIGH	MODERATE	LOCALLY HIGH MODERATE			LOW
TERRESTRIAL ECOLOGY	• SSSI Wye Valley	• Careful planning needed as infrastructure located within SSSI	• Unknown impact of increased medium flows on terrestrial sites	• No information on wetlands/riparian areas but unlikely to be affected by moderate increases in flow	• Dependent on site specific data	
Assessment	HIGH	MODERATE	MODERATE			LOW
RECREATION AMENITY NAVIGATION	• Water sports • Important tourism/amenity area	• Disturbance of suspended solids	• Could affect angling • May affect water sports	• Detailed examination of river use	• Limit on flows, velocities and levels	
Assessment	MODERATE	LOW	MODERATE			LOW

Ref: 84.247.0/AW/3122/NRAFRAME.R02

OPTION 4: Vyrnwy Redeployment for Regulation of Severn (300 Ml/d max regulation release)
REACH: River Vyrnwy to River Severn
TRANSFER: 300 Ml/d

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1A	• Tunnel construction could affect river	• Already regulated • Changes in temperature and water quality	• Detailed water quality studies needed	• Careful tunnel construction • Controlled drawoff	
Assessment	HIGH	LOW	LOW			LOW
FISHERIES	• Important salmonid area • Majority of Severn salmon redds in Vyrnwy	• Disturbance of suspended solids	• Low flow changed by 6 x Q_{95}, seasonality changed • Risk to stable nursery areas • Risk to substrate and channel characteristics	• Detailed studies of channel configuration required	• Consideration should be given to development of stream stability • Alternative release arrangements to Tanat or release further downstream	
Assessment	HIGH	LOW	HIGH			LOW
AQUATIC ECOLOGY	• Biological Class A	• Disturbance of suspended solids	• Possible washout of macroinvertebrates, etc. with continuous high releases • High local risk, moderate regional risk	• Detailed study of effects of present regulation needed	• Multiple draw-offs to mitigate temperature and water-quality problems	
Assessment	HIGH	LOW	MODERATE			LOW
TERRESTRIAL ECOLOGY	• Detailed information not available	• Tunnel construction may disturb habitats		• No information on wetlands and riparian areas	• Dependent on site specific data	
Assessment	UNKNOWN	LOW	LOW			LOW
RECREATION AMENITY NAVIGATION	• Detail not available	• Disturbance of suspended solids	• Could affect angling • May affect water sports	• Detailed examination of river use	• Limit on flows, velocities and levels	
Assessment	LOW	LOW	LOW			LOW

OPTION 5: South West Oxfordshire Reservoir Regulating Thames

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION POTENTIAL	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
Agriculture	• Land grade 3 & 4	• Significant areas of land lost		• Agricultural assessment required	• Compensation	
Assessment	MODERATE	MODERATE	LOW			N/A
Community Impacts	• Close proximity to several villages affected • 10-20 properties affected	• Access problems • Noise, disturbance		• Detailed surveys required	• Compensation	• Creation of local new road system
Assessment	HIGH	HIGH	MODERATE			LOW
Archaeology and Cultural Heritage	• No scheduled Ancient Monuments • No listed buildings directly affected	• A number of sites will be lost • Could affect setting of Venn Mill		• Archaeological survey required	• Recording excavation	• Detailed survey undertaken before inundation
Assessment	MODERATE	MODERATE	LOW			LOW
General Landscape Character	• No designations apply to the site	• Major intrusion on flat landscape		• Landscape assessment required	• Sensitive design	
Assessment	LOW	MODERATE	MODERATE			LOW
Terrestrial Ecology	• No SSSIs or sites of county importance	• Need to consider potential risks to Barrow Farm SSSI		• Detailed ecological survey required	• Habitat creation	• Creation of wetland + other habitats around the reservoir
Assessment	LOW	LOW	LOW			HIGH
Recreation/ Amenity		• Possible loss or diversion of footpaths				• Considerable recreation potential
Assessment	LOW	LOW	LOW			HIGH

Note: No specific details available relating to this option.

OPTION 5: South West Oxfordshire Reservoir Regulating Thames (350 Ml/d max)
REACH: River Thames downstream of Culham Reach
TRANSFER: 350 Ml/d

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1B	• Tunnel and intake construction could affect river	• Depends on quality or released water	• Results of WQ studies not available	• Operation of reservoir to limit water quality change	• Increased dilution of middle Thames
Assessment	HIGH	MODERATE	HIGH			MODERATE
FISHERIES	• Good Cyprinid fishery	• Tunnel and intake construction could affect river	• Low flows Q_{95} increased by >50% • Loss of October/November freshets would have adverse impacts	• Loss of early winter spates could have adverse impacts • Present knowledge of Thames fisheries	• Operating rules for abstraction should maintain October/November spates (ensure normal river rise)	• Maintenance of low flows in dry periods
Assessment	MODERATE	MODERATE	HIGH			MODERATE
AQUATIC ECOLOGY	• Biological Class A • High BMWP score	• Tunnel and intake construction could affect river	• Loss of October/November freshets could have adverse effects	• Present knowledge of Thames ecology	• High-flow capping should only be allowed between mid-Nov and June	
Assessment	HIGH	LOW	LOW			LOW
TERRESTRIAL ECOLOGY	• SSSIs downstream • Sites of County importance	• Tunnel and intake construction could affect habitats	• Wetland sites should not be adversely affected if frequency of winter flooding maintained	• Effects of higher river levels on riparian areas - drainage	• Frequency of winter flooding should not be reduced	
Assessment	HIGH	LOW	LOW			LOW
RECREATION AMENITY NAVIGATION	• Statutory navigation • High landscape value	• Tunnel and intake construction could affect river	• High velocities could affect upstream boat traffic		• Limit velocities to below navigation threshold	• Slight improvement in navigation
Assessment	HIGH	LOW	LOW			MODERATE

Ref:. 84.247.0/AW/3122/NRAFRAME.R02

OPTION 6: Canal Transfer Severn to Thames
REACH: BWB Canals - Heywood Junction to Isis Lock
TRANSFER: 100 Ml/d

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1B/2/3	• Dredging of canals likely to affect water quality - heavy metals	• Dependent on frequency of operations	• WQ of final discharge needs modelling • Transfer of heavy metals from canal sediments	• Provision of sources along canal to improve WQ prior to transfer	• Potential for class improvement in canals
Assessment	MODERATE	MODERATE	LOW			HIGH
FISHERIES	• Good coarse fisheries in places	• Dredging of canals, impact of sediments, heavy metals	• Zander spread speeded up	• Fisheries response to changes in velocity needs investigation	• Sufficient time for flow/velocity changes	• WQ improvements • Create improved environment for coarse fish
Assessment	MODERATE	HIGH	MODERATE			MODERATE
AQUATIC ECOLOGY	• Variable	• Dredging may impact on instream ecology	• Existing water slow moving and eutrophic			• Improvement in canal corridor
Assessment	MODERATE	MODERATE	LOW			LOW
TERRESTRIAL ECOLOGY	• Several stretches are of ecological value	• Loss of vegetation due to raised banks	• Loss of vegetation due to raised banks	• Survey work required	• Careful design and construction	• Restoration/ improvement works could improve adjacent areas
Assessment	MODERATE	MODERATE	MODERATE			LOW
RECREATION AMENITY NAVIGATION	• Prime function is for navigation	• Impact on boat movements during construction period	• Velocities must be kept suitable for navigation	• Scheduling of works to minimise impact	• Careful design of works and scheduling of works	• Restoration/ improvement works should improve towpaths, etc.
Assessment	HIGH	MODERATE	LOW			MODERATE

OPTION 6: Canal Transfer Severn to Thames
REACH: River Thames downstream of Oxford Canal
TRANSFER: 100 Ml/d max.

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1B	• May be problems of dredged materials in suspension, or heavy metals	• Risk of heavy metal transfer • Class risk	• Sediment qualities • Detailed WQ study for Thames • Dependent on operational use	• Care in design and construction • Limit on velocities	
Assessment	HIGH	HIGH	HIGH			LOW
FISHERIES	• Good coarse fishery	• Disturbance of sediments	• Low flows Q_{95} increased by about 12% • High metals and poor quality water in canal system • Transfer of diseases	• Zinc and other metals require further investigation • Disease transfer risk needs study • Present knowledge of Thames fisheries		• Improved low flows
Assessment	MODERATE	LOCALLY HIGH	HIGH			LOW
AQUATIC ECOLOGY	• Biological Class A • High BMWP scores	• Disturbance of sediments	• Locally around outfall depending on water quality	• Effects of water quality • Present knowledge of Thames ecology		
Assessment	HIGH	LOW	MODERATE			LOW
TERRESTRIAL ECOLOGY	• A number of sites of nature conservation value		• Wetland sites should not be affected - winter flooding unchanged	• Effects of higher river levels on riparian areas - drainage	• Frequency of winter flooding not altered	
Assessment	HIGH	LOW	LOW			LOW
RECREATION AMENITY NAVIGATION	• Statutory navigation • High landscape value	• Disturbance of sediments	• Unlikely to raise velocities above navigation limit • Could affect angling	• Effects of water quality		• Improved low flows
Assessment	HIGH	LOW	LOW			LOW

OPTION 7: **Severn to Trent Transfer to Supply East Midlands**
REACH: **River Penk downstream of Penkridge to River Sow confluence**
TRANSFER: **100 Ml/d max.**

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 2	• Disturbance during construction	• Transfer is of Class 1B water	• Detailed water quality studies needed		• Potential for class improvement
Assessment	MODERATE	LOW	LOW			HIGH
FISHERIES	• Moderate coarse fishery	• Disturbance of suspended solids	• Low flows increased by factor of 2.5 x Q_{95} • Change in seasonality of river • Minor risk of washout of coarse fry	• Detailed baseline survey required	• Velocities should be limited to reduce scour	• Flow and WQ improvements • Improved summer angling possible
Assessment	MODERATE	LOW	MODERATE			MODERATE
AQUATIC ECOLOGY	• Biological Class C • Low BMWP	• Disturbance of suspended solids	• Risk of significant change in invertebrate community • Possible bank erosion	• Baseline survey required		
Assessment	LOW	LOW	MODERATE			LOW
TERRESTRIAL ECOLOGY	• No information available		• Unlikely to be any significant impact	• Site surveys required - no information		
Assessment	UNKNOWN	LOW	LOW			LOW
RECREATION AMENITY NAVIGATION	• No information available	• Local disturbances during construction	• Channel improvements already undertaken	• Site surveys required - no information		
Assessment	UNKNOWN	LOW	LOW			LOW

OPTION 7: Severn to Trent Transfer to Supply East Midlands
REACH: River Sow downstream of Brancote to Confluence with River Trent
TRANSFER: 100 Ml/d max.

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 2	• Disturbance during construction	• Transfer is of Class 1B water	• Detailed water quality studies needed		• Improved dilution with higher quality water
Assessment	MODERATE	LOW	LOW			HIGH
FISHERIES	• Moderate Cyprinid fishery	• Local disturbance of suspended solids	• Low flows 2 x Q_{95} • Change in seasonality • Risk of fry washout	• No fisheries surveys available. Baseline survey required	• Velocity should be limited to reduce scour	• Improved dilution with higher quality water
Assessment	MODERATE	LOW	LOW			MODERATE
AQUATIC ECOLOGY	• Class C	• Local disturbance of suspended solids	• Some risk of change to invertebrate community	• Baseline survey required		• Benefit to moderate flow regime in dry periods
Assessment	LOW	LOW	LOW			MODERATE
TERRESTRIAL ECOLOGY	• No information available		• Unlikely to be any significant risk	• Site surveys required - no information		
Assessment	UNKNOWN	LOW	LOW			LOW
RECREATION AMENITY NAVIGATION	• No information available	• Local disturbance during construction		• Site surveys required - no information		• Reliable flows should improve aesthetics/ amenity at Sow/Trent confluence
Assessment	UNKNOWN	LOW	LOW			MODERATE

OPTION 7: Severn to Trent Transfer to Supply East Midlands
REACH: River Trent downstream of Great Heywood
TRANSFER: 100 Ml/d max.

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 2	• Local disturbance at intake sites	• Transfer is of Class 1B water	• Detailed water quality studies needed		• Improved flow and quality
Assessment	MODERATE	LOW	LOW			MODERATE
FISHERIES	• Coarse fishery	• Local disturbance at intake sites	• Low flows 1.5 x Q_{95} • Improved quality • Risk of disease transfer	• Baseline survey required • Review fish disease transfer issue		
Assessment	MODERATE	LOW	LOW			MODERATE
AQUATIC ECOLOGY	• Class C	• Local disturbance at intake sites		• Baseline survey required		
Assessment	LOW	LOW	LOW			MODERATE
TERRESTRIAL ECOLOGY	• Several sites of County importance	• Local disturbance at intake sites	• Unlikely to be any significant risk	• Site surveys required		
Assessment	MODERATE	LOW	LOW			MODERATE
RECREATION AMENITY NAVIGATION	• Water sports	• Local disturbance at intake sites	• Unlikely to be any significant risk	• Site surveys required - no information		
Assessment	MODERATE	LOW	LOW			MODERATE

OPTION 8: Great Bradley Reservoir - Ely Ouse to Essex Transfer (105.5m AOD top water level) *

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION POTENTIAL	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
Agriculture	• Majority of the Upper Stour Valley comprises Grade 2 land	• 720 Ha lost	720 Ha lost	• Detailed evaluation of agricultural impact		
Assessment	HIGH	MODERATE	MODERATE			N/A
Community Impacts	• Close to villages of Great Bradley and Weston Green	• Effects on access • Noise disturbance • 77 Properties inundated • High visual impact	• Changed access to village • 77 Properties inundated • High visual impact		• Compensation	
Assessment	HIGH	HIGH	MODERATE			N/A
Archaeology and Cultural Heritage	• No scheduled Ancient Monuments but a variety of archaeo-logical sites of importance • 17 Listed buildings	• Impacts of local groundwater levels • 5 Listed buildings inundated	• 5 Listed buildings inundated	• Detailed archaeological survey required	• Field survey and recording	• Detailed survey undertaken before inundation
Assessment	HIGH	LOW	MODERATE			LOW
General Landscape Character	• Located in an "Area of Best Landscape" • Ancient Countryside of the Upper Stour Valley	• Major visual impact	• Permanent change to existing views • Proximity of reservoir to villages	• Detailed assessment of the significance of landscape and visual effects on landscape character, occupiers, users and the setting of listed buildings	• Landscape proposals include woodland planting, reinforcement of existing vegetation • Intermittent tree planting	• Reservoir may create pleasant landscape feature • Improvement in river below reservoir
Assessment	MODERATE	MODERATE	MODERATE			MODERATE

* Alternative smaller reservoir would have significantly less impact

OPTION 8: Great Bradley Reservoir - Ely Ouse to Essex Transfer (Cont'd)

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION POTENTIAL	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
Terrestrial Ecology	• Presence of numerous nationally important sites (SSSI)	• Inundation of four (SSSIs) Ancient Woodlands and five further Ancient Woodlands	• Impacts on SSSIs	• Full survey required	• Setting aside equivalent areas of land for plantation of woodland (not satisfactory)	• Nature conservation opportunities around new reservoir
Assessment	HIGH	MODERATE	MODERATE			MODERATE
Recreation/ Amenity	• Area is popular with walkers, horse-riders • Wealth of public rights of way	• Inundation of numerous footpaths		• Full survey required	• Establish new footpaths, nature trails, amenities	• Significant recreational opportunities • Contribution to local economy, angling, walking, cycling, horse-riding, sailing and wind surfing
Assessment	MODERATE	LOW	MODERATE			HIGH

* Alternative smaller reservoir would have significantly less impact

OPTION 8: Great Bradley Reservoir - Ely Ouse to Essex Transfer
REACH: Tidal Ely Ouse Downstream of Denver Sluice, Ouse Estuary and The Wash

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• Class A estuary		• For existing PF of 318 to 114 Ml/d	• Further studies required for min. PF to estuary and The Wash	• Appropriate PF	
Assessment	HIGH	N/A	LOW			N/A
FISHERIES	• Migratory fish, eels, sea trout • Shell fisheries • Shrimp fisheries		• For existing PF of 318 to 114 Ml/d	• Further studies required for min. PF to estuary and The Wash	• Appropriate PF	
Assessment	HIGH	N/A	HIGH			N/A
AQUATIC ECOLOGY	• Tidal river of low value • The Wash is a RAMSAR site, SSSI and SPA*		• For existing PF of 318 to 114 Ml/d	• Further studies required for min. PF to estuary and The Wash	• Appropriate PF	
Assessment	HIGH	N/A	LOW			N/A
TERRESTRIAL ECOLOGY	• Ouse Washes SSSI • Water meadows			• Further studies required for min. PF to estuary and The Wash	• Appropriate PF	
Assessment	HIGH	N/A	LOW			N/A
RECREATION AMENITY NAVIGATION	• Kings Lynn Port • River ferry • Water sports • Cruising			• Further studies required for min. PF to estuary and The Wash	• Appropriate PF	
Assessment	HIGH	N/A	HIGH			N/A

* Special Protection Area under EC Directive on conservation of wild birds

Note: Low impacts provided prescribed flow set at appropriate level

OPTION 8: Great Bradley Reservoir - Ely Ouse to Essex Transfer
REACH: River Stour
TRANSFER: 309 Ml/d max. transfer

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 2	• Construction of reservoir/intake, river training may affect river	• Greater scale of transfer • Improvement of transfer WQ by storage	• Degree to which operations features of reservoir to improve WQ • Incidence of high chloride water from Ely Ouse • Detailed studies of effects of present regulation needed	• Ensure high chloride waters not transferred - engineering works/ management at Denver	• Improved dilution of poor catchment water quality
Assessment	LOW	LOW	MODERATE			MODERATE
FISHERIES	• Coarse fishery downstream	• Disturbance of suspended solids	• Major increase in low flows, change in seasonality • Major change in water quality	• Actual operation and quantities of transfer within Essex system is unknown • Examine risk of disease transfer	• Reproduce flow seasonality/ variability	• Greater flow stability and improved water quality could benefit fisheries
Assessment	MODERATE	LOCALLY HIGH MODERATE	MODERATE			MODERATE
AQUATIC ECOLOGY	• Biological Class A at Ketling Green • Artificial channel	• Disturbance of suspended solids	• Magnitude and frequency of flows in excess of existing scheme, likely further scour and washout	• Major impact but small river already substantially altered by existing transfers	• Further degradation only acceptable if other rivers in region retain their high degree of naturalness	• Channel improvements could enhance present character and conditions
Assessment	MODERATE/HIGH	MODERATE	LOCALLY HIGH MODERATE			MODERATE
TERRESTRIAL ECOLOGY	• No SSSIs	• Civil works may be required along river banks	• Unlikely to be significant risk	• Site surveys required - no information		• Channel improvements could enhance present character and conditions
Assessment	MODERATE	MODERATE	LOW			MODERATE

Note: Assessment based on existing regulated conditions, not on baseline of natural conditions.

OPTION 8: Great Bradley Reservoir - Ely Ouse to Essex Transfer
REACH: River Stour
(Cont'd)

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
RECREATION AMENITY NAVIGATION	• Ancient landscape area of great landscape value (Constable Country) • Canoeing	• River training works will affect users	• Effect on visual amenity would be high in Lower Stour • Likely significant affect on angling • Flows very high could affect water-sports	• Very high flows in Lower Stour may be unacceptable • Visual amenity	• Pipe water rather than use river transfer • Limit flows to user acceptable limit	• Channel improvements could enhance present character and conditions
Assessment	HIGH	MODERATE	MODERATE			MODERATE

Note: Assessment based on existing regulated conditions, not on baseline of natural conditions.

OPTION 8: Great Bradley Reservoir - Ely Ouse to Essex Transfer
REACH: River Pant/Blackwater
TRANSFER: 305 Ml/d max. transfer

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1B	• Construction of intake/discharge/ training works may affect river	• Greater scale of transfer • Risk of poor transfer quality • Improvement of transfer WQ by storage	• Precise operating rules unknown • Incidence of high chloride water from Ely Ouse	• Ensure high chloride waters not transferred - engineering works/ management at Denver	• Already substantially altered by existing transfers • Water quality of transfers improved by storage
Assessment	MODERATE	LOW	MODERATE			MODERATE
FISHERIES	• Coarse fishery downstream	• Disturbance of suspended solids	• Major low flow/ quality changes • Risk of change to species composition		• Reproduce flow seasonality variability	• Greater flow stability and improved water quality could benefit fisheries
Assessment	MODERATE	MODERATE	HIGH			MODERATE
AQUATIC ECOLOGY	• Biological Class A • Artificial character	• Disturbance of suspended solids	• Already heavily artificial flow but significant flow increase, enhanced scour and washout • High local risk at discharge	• If channelisation works involved these will have major impact	• Further degradation only acceptable if other rivers retain their high degree of naturalness	• Channel improvements could enhance present character and conditions
Assessment	HIGH	MODERATE	LOCALLY HIGH MODERATE			MODERATE
TERRESTRIAL ECOLOGY	• No sites identified	• Civil works may be required along river banks	• Unlikely to be significant impact	• Channelisation works would need to be surveyed • Site surveys needed		• Channel improvements could enhance present character and conditions
Assessment	LOW	MODERATE	LOW			MODERATE

Note: Assessment based on existing regulated conditions, not on baseline of natural conditions.

Ref: 84.247.0/AW/3122/NRAFRAME.R02

OPTION 8: Great Bradley Reservoir - Ely Ouse to Essex Transfer
REACH: River Pant/Blackwater
(Cont'd)

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
RECREATION AMENITY NAVIGATION	• Mill of historic interest • Landscape	• River training works will affect river	• Long term landscape implications during transfers • Likely significant effect on angling • Effect on water sports	• Very high flows in Lower Blackwater could be unacceptable	• Pipe water rather than use river transfer • Limit flows to user acceptable limit	• Channel improvements could enhance present character and conditions
Assessment	HIGH	MODERATE	MODERATE			MODERATE

Note: Assessment based on existing regulated conditions, not on baseline of natural conditions.

OPTION 9: **Unsupported Trent to Essex**
REACH: **River Witham (Junct. with Fossdyke Navigation at Lincoln to Boston and Fossdyke Navigation)**
TRANSFER: **200 Ml/d additional to 220 Ml/d existing**

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 2	• Local disturbance on Fossdyke Navig. and at Boston intake	• Transfer of pollutants • Dilution of ammonia, nitrate, chloride	• Further investigate water quality	• Channel improvement works	• Improved dilution
Assessment	MODERATE	LOW	MODERATE			LOW
FISHERIES	• Coarse fishery downstream	• Local disturbance on Fossdyke Navig. and at Boston intake	• Possible effects on fisheries, particularly on Fossdyke; due to flow changes up to 4 x Q_{95} • WQ risks could be significant • Potential transfer of Zander	• Habitat should remain favourable but uncertainties associated with changing low flow regime, could be species changes • Effects on scour		
Assessment	MODERATE	LOW	MODERATE			LOW
AQUATIC ECOLOGY	• Artificial channel • No specific information	• Local disturbance on Fossdyke navig. and at Boston intake	• No major risks envisaged • Likely change in aquatic fauna in Fossdyke	• Further study required of impact of ortho-phosphates and metals	• Channel works could be used to increase diversity	
Assessment	LOW	LOW	MODERATE			LOW
TERRESTRIAL ECOLOGY	• No SSSIs	• Local disturbance on Fossdyke Navig. and at Boston intake • Bank raising, new channels could affect areas	• Major risks unlikely	• Site survey required - no information available	• Care in design and construction	• Habitat creation opportunities in engineering works
Assessment	LOW	LOW	LOW			LOW

OPTION 9: Unsupported Trent to Essex
REACH: River Witham (Junct. with Fossdyke Navigation at Lincoln to Boston and Fossdyke Navigation)
(Cont'd)

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
RECREATION AMENITY NAVIGATION	• Statutory Navigation, popular boating • Canoeing, visual amenity	• Local disturbance on Fossdyke Navig. and at Boston intake	• Velocities in Fossdyke and Witham may exceed navigation limit	• Detailed surveys required	• Use of Sincil Dyke to divert excess flows at Lincoln • Limit velocities to navigation needs	
Assessment	HIGH	LOW	MODERATE			LOW

OPTION 9: **Unsupported Trent to Essex via Ely Ouse to Essex Scheme**
REACH: **River Stour (Kirtling Green Outfall to Wixoe intake and d/s of Wixoe)**
TRANSFER: **200 Ml/d additional transfer**

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 2	• Local disturbance at discharge/intake	• No improvement in class expected	• Further water quality studies needed	N/A	• Improved dilution of poor catchment water quality
Assessment	LOW	LOW	MODERATE			LOW
FISHERIES	• Coarse fishery downstream	• Local disturbance at discharge/intake	• Very significant flow increase • Change in seasonality • Change in water quality	• Actual operation and transfer details not known	• Reproduce flow seasonality/ variancy	
Assessment	MODERATE	MODERATE	MODERATE			LOW
AQUATIC ECOLOGY	• Biological Class A • Artificial channel	• Local disturbance at discharge/intake	• Magnitude of flows in excess of existing scheme	• Major impact but small river already substantially altered by existing transfers	• Potential for re-shaping river channel	• Channel improvements could enhance present character and conditions
Assessment	MODERATE/HIGH	MODERATE	MODERATE			MODERATE
TERRESTRIAL ECOLOGY	• No SSSIs	• Risks may arise if river training required	• Unlikely to be major risks	• Site surveys required - no information		• Channel improvements could enhance areas
Assessment	MODERATE	MODERATE	LOW			MODERATE
RECREATION AMENITY NAVIGATION	• Ancient countryside (Constable Country) • Canoeing	• River training works will affect users	• Major effect on angling • Major effect on amenity in Lower Stour	• Algal growth • Turbidity • W/L changes • V.high flows in Lower Stour would be unacceptable	• Pipe water rather than use river transfer • Limit flows to user acceptable limits	• Channel improvements could enhance areas
Assessment	HIGH	MODERATE	MODERATE			MODERATE

Note: Assessment based on existing regulated conditions, not on baseline of natural conditions.

OPTION 9: Unsupported Trent to Essex via Ely Ouse to Essex Scheme
REACH: River Pant/River Blackwater d/s of Gt Sampford Outfall
TRANSFER: 200 Ml/d

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 1B	• Construction of intake/discharge/ training works may affect river	• Risk of poor quality transfer • Transfer of pollutants	• Further investigate water quality	• Transfer only when water quality suitable	
Assessment	MODERATE	LOW	MODERATE			LOW
FISHERIES	• Coarse fishery downstream	• Construction of intake/discharge/ training works may affect river	• Very significant flow changes • Increased flows likely to affect coarse fishery • Scour and washout	• Actual operations and transfer details not known	• Limit flows and velocities to species limits	
Assessment	MODERATE	MODERATE	MODERATE			LOW
AQUATIC ECOLOGY	• Biological Class A • Artificial channel	• Construction of intake/discharge/ training works may affect river	• Already heavily channelised and artificial flows • Significant habitat changes likely	• If channelisation works required these will have major impact • Algal blooms may occur		• Channel improvements could enhance present character and conditions
Assessment	HIGH	MODERATE	LOCALLY HIGH MODERATE			MODERATE
TERRESTRIAL ECOLOGY	• No sites identified	• Construction of intake/discharge/ training works may affect river	• Unlikely to be significant risks	• Channelisation work would need to be surveyed		• Channel improvements could enhance present character and conditions
Assessment	LOW	MODERATE	LOW			MODERATE

Note: Assessment based on existing regulated conditions, not on baseline of natural conditions.

Ref: 84.247.0/AW/3122/NRAFRAME.R02

OPTION 9: Unsupported Trent to Essex via Ely Ouse to Essex Scheme
REACH: River Pant/River Blackwater d/s of Gt Sampford Outfall
(Cont'd)

RECREATION AMENITY NAVIGATION	• Mill of historic interest • Landscape	• Construction of intake/discharge/ training works may affect river	• Long term landscape implications during transfers • Likely significant affect on angling • Effect on water sports	• Very high flows in Lower Blackwater could be unacceptable	• Pipe water rather than use river transfer • Limit flows to user acceptable limit	• Channel improvements could enhance present character and conditions
Assessment	MODERATE	MODERATE	MODERATE			MODERATE

Note: Assessment based on existing regulated conditions, not on baseline of natural conditions.

Ref:. 84.247.0/AW/3122/NRAFRAME.R02

OPTION 9: Unsupported Trent to Essex via Ely Ouse to Essex Scheme
REACH: Trent d/s Torksey
TRANSFER: 200 Ml/d

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• NWC Class 2 • Power station use	• Local disturbance during construction	• Abstraction 10% of preliminary PF • Effects will be small	• Further studies required of minimum PF to estuary and Humber estuary	• Appropriate PF; preliminary idea 2500 Ml/d?	
Assessment	MODERATE	LOW	MODERATE			N/A
FISHERIES	• Poor coarse fishery • Potential migratory salmon route	• Local disturbance during construction	• Abstraction 10% of preliminary PF • Effects will be small	• Further studies required of minimum PF to estuary and Humber estuary • Baseline survey required	As above	
Assessment	LOW	LOW	LOW			N/A
AQUATIC ECOLOGY	• Impoverished, low biodiversity • BMWP 92 • ASPT 4.20	• Local disturbance during construction	• Abstraction 10% of preliminary PF • Effects will be small	• Further studies required of minimum PF to estuary and Humber estuary • Baseline survey required	As above	
Assessment	LOW	LOW	LOW			N/A
TERRESTRIAL ECOLOGY	• No information available	• Local disturbance during construction	• Abstraction 10% of preliminary PF • Effects will be small	• No information on wetlands/riparian areas but unlikely to be affected by small changes	As above	
Assessment	LOW	LOW	LOW			N/A
RECREATION AMENITY NAVIGATION	• Statutory navigation	• Local disturbance during construction	• Abstraction 10% of preliminary PF • Effects will be small	• Further studies required of min. PF to estuary and Humber estuary • Baseline survey needed	As above	
Assessment	HIGH	LOW	MODERATE			N/A

Note: No impacts provided prescribed flow set at appropriate level.

OPTION 10: **Broad Oak Reservoir**
REACH: **Sarre Penn downstream of reservoir**
TRANSFER: **Unknown**

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• Ephemeral tidally influenced stream	• Local disturbance from works	• Damming headwaters would reduce dilution flows and risks saline intrusion	• Whether compensation releases will be made	• Compensation releases down Sarre Penn	
Assessment	LOW	MODERATE	MODERATE			MODERATE
FISHERIES	• Fisheries status unknown but unlikely to be of major importance	• Local disturbance from works		• Whether compensation releases will be made	• Compensation releases down Sarre Penn, reproduce flow seasonality and variability	
Assessment	LOW	MODERATE	MODERATE			LOW
AQUATIC ECOLOGY	• Unknown biological status	• Local disturbance from works	• Understood to be tidally influenced stream	• Whether compensation releases will be made	• Compensation releases down Sarre Penn, reproduce flow seasonality and variability	
Assessment	LOW	MODERATE	MODERATE			LOW
TERRESTRIAL ECOLOGY	• SNCI Marshland	• Local disturbance from works		• Whether compensation releases will be made	• Compensation releases down Sarre Penn, reproduce flow seasonality and variability	
Assessment	LOW	LOW	MODERATE			LOW
RECREATION AMENITY NAVIGATION	• Landscape value understood not to be of major importance	• Local disturbance from works		• Whether compensation releases will be made	• Compensation releases down Sarre Penn, reproduce flow seasonality and variability	• Improve visual amenity
Assessment	LOW	MODERATE	MODERATE			LOW

Note: Low impacts provided compensation flow is set at appropriate level.

OPTION 10: **Broad Oak Reservoir**
REACH: **River Stour and Estuary downstream of Plucks Gutter**
TRANSFER: Unknown

CATEGORY	SENSITIVITY	RISK OF IMPACT		UNCERTAINTIES AND STUDY REQUIREMENTS	MITIGATION	BENEFIT OPPORTUNITIES
		Constr.	Oper.			
WATER QUALITY	• Class A Estuary	• Local disturbance from intake works	• Estuary to be protected by setting PF	• Details of operating rules • Further studies required of min. PF to estuary	• Appropriate PF d/s of Plucks Gutter, 149 to 89 Ml/d being considered	
Assessment	HIGH	MODERATE	LOW			N/A
FISHERIES	• Coarse fishery	• Local disturbance from intake works	• Estuary to be protected by setting PF	• Maintenance of autumn freshets under operating rules - spate sparing	• Need to maintain freshets to estuary in autumn to ensure normal river rise	
Assessment	MODERATE	MODERATE	LOW			N/A
AQUATIC ECOLOGY	• Moderate BMWP Class B	• Local disturbance from intake works	• Estuary to be protected by setting PF	• Further studies required • Detailed	• Appropriate PF	
Assessment	MODERATE	MODERATE	LOW			N/A
TERRESTRIAL ECOLOGY	• Great Stour Nature Reserve • Water meadows	• Local disturbance from intake works	• Risk of saline intrusion to be offset by PF setting	• Impacts on Ash levels & 5 months pasture require investigation • Effects on drainage areas	• Appropriate PF	
Assessment	LOW	LOW	LOW			N/A
RECREATION AMENITY NAVIGATION	• Pleasant landscape	• Local disturbance from intake works	• Estuary to be protected by setting PF		• Appropriate PF	
Assessment	LOW	LOW	LOW			N/A

Note: Low risks provided prescribed flow is set at appropriate level.

APPENDIX E

Bibliography

NRA NATIONAL WATER RESOURCES STRATEGY
STRATEGIC ENVIRONMENTAL ASSESSMENT

BIBLIOGRAPHY

Alabaster, J.S., 1976. The Water Quality Aspects of Water Transfer. Chemistry and Industry, Vol. 21.

Alabaster, J.S. and Lloyd, R., 1982. Water Quality Criteria and Freshwater Fish, Food and Agriculture Organisation of the United Nations, Butterworth Scientific.

Alderman, D J and Wickins, J F (1990). *Crayfish Culture*. Laboratory leaflet number 62. Directorate of fisheries research, MAFF.

Armitage, P D and Petts, G E, 1992. "Biotic Score and Prediction to Assess the Effects of Water Abstractions on River Macroinvertebrates for Conservation Purposes", Aquatic Conservation: Marine and Freshwater Ecosystems, 2, 1-17.

Armitage, P.D., 1978. Downstream Changes in the Composition, Numbers and Biomass of Bottom Fauna in the Tees below Cow Green Reservoir and in an Unregulated Tributary Maize Beck in the First Five Years After Impoundment, Hydrobiologia, 58, 145-156.

Armitage, P.D. and Ladle, M., 1989. Habitat preferences of target species for application of PHABSIM testing. In Bullock, A, Gustard, A and Grainger, E&S (19[illegible]). Instream Flow Requirements of Aquatic Ecology in Two British Rivers. Institute of Hydrology, Wallingford, UK.

Armitage, P.D., R.J.M. Gunn, M.T. Furse, J.F. Wright and D. Moss, 1987. The Use of Prediction to Assess Macroinvertebrate Response to River Regulation. Hydrobiologia 144:25-32.

Armitage, P.D. and Ladle, M. 1991. Habitat preferences of target species for application of PHABSIM testing. In Bullock, A, Gustard, A and Grainger, E S (1991). Instream Flow Requirements of Aquatic Ecology in Two British Rivers. Institute of Hydrology, Wallingford, UK.

Armitage, P D and Ladle, M (1991). *Habitat preferences of target species for application of PHABSIM testing.* In Bullock, A, Gustard, A and Grainger, E S (1991). *Instream Flow Requirements of Aquatic Ecology in Two British Rivers.* Institute of Hydrology.

Asian Development Bank, 1988. Guidelines for Integrated Regional Economic-cum-Environmental Development Planning - A Review of Regional Environmental Development Planning Studies in Asia, Volume 1, ADB, Manila, The Philippines.

Bass, R., 1991. Policy, Plan and Programme EIA in California, EIA Newsletter 5, 4-5.

Bass, R., 1990. California's Experience with Environmental Impact Reports, Project Appraisal, 220-224.

Batten, L A, Bibby, C J, Clement, P, Elliott, G D and Porter, R F (1990). ***Red Data Birds in Britain***. NCC and RSPB.

Baxter, R.M., 1977. Environmental Effects of Dams and Impoundments, Ann. Rev. Ecol. Syst., 8.

Bell, A., 1988. EIA in Forward Planning: The Cheshire Experience, in Clark, M. and Herington, J. (eds.), The Role of EIA in the Planning Process, Mansell, London.

Betts, REF in EIA library

Binnie and Partners/Oakwood Environmental, 1991. Water for the Future in Kent: Issues and Options, Binnie and Partners, Redhill, Surrey.

Bisset, R., 1988. Developments in EIA Methods, in Wathern,P. (ed.), Environmental Impact Assessment: Theory and Practice, Routledge, London.

Boniface, E.S., 1959. Some Experiments in Artificial Recharge in the Lower Lee Valley, Proc. Inst. Civ. Engrs., 14, 325-338.

Boon, P.J., 1976. An ecological Study of the River Colne during a Trial Discharge from the Ely-Ouse Inter-River Transfer System, unpublished report, Polytechnic of the South Bank, London.

Boon, P J, 1991. Environmental Impact Assessment and the Water Industry: Implications for Nature Conservation, J. IWEM, pp 194-205.

Boon, P J, 1992. "Essential Elements in the Case for River Conservation", in Boon, P. J., Calow, P. and Petts, G. E. (eds), River Conservation and Management, John Wiley and Sons, Chichester, 10-33.

Boon, P J, 1988. "The Impact of River Regulation on Invertebrate Communities in the UK", Regulated Rivers: Research and Management, 2, 389-409.

Brown, R.P.C., Ironside, N. and Johnson, S. 1991. Defining an Environmentally Acceptable Flow Regime for the River Darent, Kent. Proceedings of the Third National Hydrology Symposium, University of Southampton 16-18th September 1991. British Hydrological Society.

Brown, R P C, Ironside N and Johnson S, 1991. Defining an environmentally acceptable flow regime for the River Darent, Kent. In proceedings of the 3rd National BHS Symposium, Southampton. British Hydrological Society.

Brown, R.P.C., Ironside, N. and Johnson, S. 1991. Defining an Environmentally Acceptable Flow Regime for the River Darent, Kent. Proceedings of the Third National Hydrology Symposium, University of Southampton 16-18th September 1991. British Hydrological Society.

Bryan, K A (1981). An investigation of some factors influencing the performance of a recreational trout fishery. *Journal of Applied Ecology*.

Bullock, A., Gustard, A. and Grainger, E.S. 1991. Instream Flow Requirements of Aquatic Ecology in Two British Rivers. Institute of Hydrology, Report No. 115.

Bullock, A., Gustard, A. and Grainger, E.S. 1991. Instream Flow Requirements of Aquatic Ecology in Two British Rivers. Institute of Hydrology.

Bullock, A. and Johnson, I. 1991. Towards the setting of Ecologically Acceptable Flow Regimes with IFIM. Proceedings of the Third National Hydrology Symposium, University of Southampton 16-18th September 1991. British Hydrological Society.

Bullock, A. and Johnson, I. 1991. Towards the setting of Ecologically Acceptable Flow Regimes with IFIM. Proceedings of the Third National Hydrology Symposium, University of Southampton 16-18th Septemberá 1991. British Hydrological Society.

Bullock, A, Gustard, A and Grainger, E S (1991). *Instream Flow Requirements of Aquatic Ecology in Two British Rivers.* Institute of Hydrology.

Bullock, A. & Gustard,A. 1991. Application of the Instream Flow Incremental Methodology to assess ecological flow requirements in a British lowland river. In Fluvial Dynamics of Lowland River Channel and Floodplain Systems, Proceedings of British Geomorphological Research Group Symposium, Loughborough, September 1990.

Butler, D. and West, J.W., 1987. Leakage Prevention and System Renewal, paper presented at Pipeline Management Symposium, 1987, Pipeline Industries Guild, London.

Butler, S (1982). *Dragonflies of Shropshire.* Caradoc And Severn Valley Field Club.

Campbell, R N B and Scott, D (1984). The determination of minimum discharge for O+ brown trout (*Salmo trutta* L.) using a velocity response. *New Zealand Journal of Marine and Freshwater Research* 1984, Vol. 18.

Carling, P. A., 1979. Survey of Physical Characteristics of Salmon Spawning Riffles in the River North Tyne, F.B.A. Teesdale Unit, Barnard Castle, Internal Report.

Carling, P, 1988. Channel Change and Sediment Transportation in Regulated UK Rivers. Regulated Rivers: Research and Management 2:369-387.

Cave, J.D., 1985. The Effects of the Kielder Scheme on Fisheries, Journal of Fish Biology, 27.

Central Water Planning Unit, 1980. Severn to Thames Water Transfers: Technical Report, HMSO, Amersham.

CIRIA, 1991. Engineering Implications of Rising Groundwater Levels in the Deep Aquifer beneath London, CIRIA, London.

Clark, B., Chapman, K., Bisset, R.,and Wathern, P., 1976. The Assessment of Major Industrial Applications: A Manual, DOE Research Report No. 13, HMSO, London.

Coles, T.F. and Tarling, J., 1991. Environmental Assessment: Experience to Date, Institute of Environmental Assessment.

Coles, T.F., Fuller, K.G.,and Tarling, J., 1992. Environmental Assessment: Experience in the UK, 1st Membership Conference, Institute of Environmental Assessment, Birmingham.

Commission of the European Communities, 1992. Towards Sustainability: Fifth Action Programme on the Environment, CEC.

Corbet, G B, and Harris, S (Eds., 1991). *The handbook of British mammals, third ed.* Blackwell.

Council for the Protection of Rural England, 1991. The Environmental Assessment Directive-Five Years On, CPRE, England.

Countryside Commission, English Heritage and English Nature, 1993. Conservation Issues in Strategic Plans, Countryside Commission, Northampton.

Cowx, I.G., W.O. Young and J.M. Hellawell, 1984. The Influence of Drought on the Fish and Invertebrate Populations of an Upland Stream in Wales. Freshwater Biol. 14:165-177.

Cowx, I.G., and Gould, R.A. 1989. Effects of stream regulation on Atlantic salmon, *(salmo salar L.),* and brown trout, *(salmo trutta L.)*, in the upper Severn catchment, UK. Regulated rivers: Research and management, Vol. 3.

Cowx, I G, Young, W O and Hellawell, J M (1984). The influence of drought on the fish and invertebrate populations of an upland stream in Wales. *Freshwater Biology* Vol. 14.

Cowx, I G, and Gould, R A (1989). Effects of stream regulation on Atlantic salmon, *(salmo salar L.),* and brown trout, *(salmo trutta L.),* in the upper severn catchment, UK. *Regulated rivers: Research and management*, Vol. 3.

CPRE, 1990. Water on Tap? The Case for Water Metering, CPRE Leaflet.

Crisp, D T (1989). Some impacts of human activities on trout, *(Salmo trutta)* populations. *Freshwater Biology* Vol. 21.

Crisp, D.T., Mann,R.H.K. & Cubby,P.R. 1983. Effects of regulation of the River Tees upon fish populations below Cow Green reservoir. Journal of Applied Ecology, 20, 371-386.

Crisp, D.T., 1985. Thermal "Resetting" of Streams by Reservoir Releases with Special Reference to Effects on Salmonid Fishes. Prepared for Freshwater Biological Association, Ambleside. Internal Report.

Crisp, D.T., 1977. Some Physical and Chemical effects of the Cow Green (Upper Teesdale) impoundment. Freshwat. Biol. 7. 109-120.

Crisp, D.T., 1984. Water Temperature Studies in the River North Tyne after Impoundment by Kielder Dam, F.B.A. Teesdale Unit, Barnard Castle, Internal Report.

Dakang, Z and Changming, L, 1981. East China Water Transfer: Its Environmental Impact. Mazingira, Volume 5, Part 4, pp 48-57.

Davies, B R, Thoms, M and Meador, M, 1992. "An Assessment of the Ecological Impacts of Inter-Basin Transfers and their Threats to River Basin Integrity and Conservation", Aquatic Conservation: Marine and Freshwater Ecosystems, 2, 325-349.

Davies, K., 1991. Notes of Discussions and Meetings on the Role of Environmental Factors in Policy Formulation and Environmental Assessment Research in the UK, FEARO, Ontario, Canada.

Dawson, F H (1978). Aquatic plant management in semi-natural streams: the role of marginal vegetation. *J. Environmental Management* 6: 213-221.

Department of the Environment, 1991. The Potential Effects of Climate Change in the UK, HMSO, London.

Department of the Environment, Welsh Office, 1992. Planning Policy Guidance Note 12,: Development Plans and Regional Planning Guidance, HMSO, London.

Department of the Environment, Welsh Office, 1992. Using Water Wisely: A Consultation Paper, DOE, London.,

Department of the Environment, 1992. PPG 12: Development Plans and Regional Planning Guidance, HMSO, London.

Department of the Environment, 1991. Policy Appraisal and the Environment, HMSO, London.

Drake, P.J. and Sherriff, J.D.F. 1987. A Method for Managing River Abstractions and Protecting the Environment. Jnl of IWEM, 1(1), pp27-38.

Drake, P.J. and Sherriff, J.D.F. 1987. A Method for Managing River Abstractions and Protecting the Environment. Journal IWEM, 1(1), 27-38.

ENDS Report, June 1992. NRA Targets Thames Water in Fight over Drying Rivers, 209, 9-10.

ENDS Report, May 1991. Opening Shots in the Debate on Strategic Environmental Assessment, 196, 18-20.

ENDS Report, June 1993. Taking Stock of Environmental Assessment, 221, 20-24.

ENDS Report, December 1992. Sustainable Development: Managing the Demand for Water, 215, 20-22.

English Nature, 1992. Strategic Planning and Sustainable Development: A Discussion Paper, Peterborough.

European Bank for Reconstruction and Development, 1992. Environmental Procedures, EBRD, London.

Fraser, J C (1975). *Determining discharges for fluvial resources.* FAO Technical Paper No. 143. Rome.

Gardiner, J. L., 1988. Environmentally Sound River Engineering: Examples from the Thames Catchment, Regulated Rivers: Research and Management, 2, 445-469.

Gardiner, J., 1992. Strategic Environmental Assessment and the Water Environment, Project Appraisal, 7(3), 1992.

Goldsmith, H. and Parry, E.L. 1991. Short and Long Term Options for Low Flow Alleviation.Proceedings of the Third National Hydrology Symposium, University of Southampton 16-18th September 1991. British Hydrological Society.

Goldsmith, H., Oxley, N.C. and Morgan, V., 1993. Abstraction for Public Water Supply and Environmental Demands on Resources, 4th National Hydrology Symposium, Cardiff.

Golubev, G N and Biswas, A K, 1984. Large-Scale Water Transfers: Emerging Environmental and Social Issues. Int. Jnl. of Water Resources Development, Volume 2, Part 2/3, pp 1-5.

Golubev, G.N., and Biswas, A.K. 1985. Large-scale Water Transfers: Emerging Environmental and Social Issues, in Biswas, A.K. (ed.) International Journal of Water Resources Development ,2(2/3), Tycooly Publishing Ltd, Oxford, England.

Golubev, G.N., and Biswas, A.K., (Eds), 1979. Inter-regional Water Transfers: Problems and Prospects. Water Development, Supply and Management, 6. Pergamon Press, Oxford, England.

Gordon, N.D., McMahon, T.A. and Finlayson, B.L. 1992. Stream Hydrology: An Introduction for Ecologists. John Wiley & Sons, England.

Gordon, N.D., McMahon, T.A. and Finlayson, B.L., 1992. Stream Hydrology: An Introduction for Ecologists. John Wiley & Sons, England.

Gore, J.A. and Judy, R.D., 1981. Predictive Models of Benthic Macroinvertebrate Density for use in Instream Flow Studies and Regulated River Management, Canadian Journal of Fisheries and Aquatic Sciences, 34,1367-1370.

Gore, J.A. and Petts, G. E. (eds.), 1989. Alternatives in Regulated River Management, CRC Press, Florida.

Gregory, KJ (1992). Vegetation and River Channel Process Interactions. In Boon, PJ, Calow, P and Petts, GE (1992). *River Conservation and Management*. Wiley.

Guiver, K., 1976. The Ely Ouse to Essex Transfer Scheme. Chemy Ind., Feb 1976, 132-135.

Gustard, A. and Bullock, A., 1991. Advances in Low Flow Estimation and Impact Assessment. Proceedings of the Third National Hydrology Symposium, University of Southampton 16-18th September 1991. British Hydrological Society.

Gustard, A. and Bullock, A. 1991. Advances in Low Flow Estimation and Impact Assessment. Proceedings of the Third National Hydrology Symposium, University of Southampton 16-18th September 1991. British Hydrological Society.

Gustard, A., 1989. Compensation Flows in the UK: A Hydrological Review. Regulated Rivers: Research & Management 3:49-59

Gustard, A., 1992. Analysis of river regimes in Callow, P. and Petts, G. E., (Eds), The Rivers Handbook.: Hydrological and Ecological Principles. Blackwell Scientific Publications, Oxford, England.

Gustard, A., G. Cole, D. Marshall and A. Bayliss, 1987. A Study of Compensation Flows in the UK. Report No. 99. Prepared for the Institute of Hydrology.

Ham, SF, Wright, JF and Berrie, AD (1982). The Effect of Cutting on the Growth and Recession of the Freshwater Macrophyte *Ranunculus pennicillatus* (Dumort.)Bab. var. *calacareus* (R.W.Butcher)C.D.K.Cook. *Journal of Environmental Management* 15:263-271.

Haslam, S M and Wolsely, P A (1981). *River vegetation: its identification, assessment and management.* Cambridge.

Hellawell, J.M, 1988. River Regulation and Nature Conservation. Regulated Rivers: Research and Management 2:425-443.

Hellawell, J.M. 1986. Biological Indicators of Freshwater Pollution and Environmental Management. Elsevier Applied Science.

Henszey, R J, Skinner, Q D and Wesche, T A (1991). Response of montane meadow vegetation after two years of streamflow augmentation. *Regulated Rivers: Research and Management*, Vol. 6.

Higgs, G. and G. Petts, 1988. Hydrological Changes and River Regulation in the UK. Regulated Rivers: Research & Management 2:349-368.

Hill, C. and Langford,T., 1992. Dying of Thirst: Aill an d angm mmmmdmdmdmdmdmmmm Response to the Problem of our Vanishing Wetlands, Royal Society for Nature Conservation and the Wildlife Trusts Partnership, Lincoln.

Holdich, D M and Lowery, RS (1988). *Freshwater Crayfish: biology, management and exploitation.* Croom Helm.

Holdich, D M and Reeve, I D (1991). Distribution of freshwater crayfish in the British Isles, with particular reference to crayfish plague, alien introductions and water quality, *Aquatic Conservation: marine and freshwater ecosystems,* vol 1, 139-158.

Holling, C.S., 1978. Adaptive Environmental Assessment and Management, John Wiley and Sons, New York.

Holmes, N. and Whitton, B.A., 1981. Phytobenthos of the River Tees and its Tributaries, Freshwater Biology, 11, 139-168.

Holmes, N and Newbold, C (1984). *River Plant Communities - reflected of water and substrate chemistry.* Focus on Nature Conservation No 9. Nature Conservancy Council.

Howard Humphreys & Partners Ltd, 1992. River Worfe Study. Stage 1 - Preliminary Study for National Rivers Authority, Severn Trent Region. March 1992.

HUD, 1981. Areawide Environmental Impact Assessment: A Guidebook, Department of Housing and Urban Development, Washington D.C.

HUD (Housing and Urban Development), 1977. Integration of Environmental Considerations in the Comprehensive Planning and Development Process, Department of Housing and Urban Development, Washington D.C.

ICOLD, 1985. Dams and the Environment, Bulletin 66, International Commission on Large Dams, Paris.

Institute of Hydrology/British Geological Survey, 1992. Hydrological Summary for Great Britain, August 1992. Institute of Hydrology, Wallingford, UK.

Institute of Hydrology, 1980. Low Flow Studies. IoH, Wallingford, UK.

Institute of Hydrology, 1991. Advances in Low Flow Estimation and Impact Assessment by Gustard A and Bullock A in Proc. Third National Hydrology Symposium, 16-18th September 1991, Southampton, BHS, UK.

Institution of Civil Engineers, 1991. Water Supplies in the UK in the 1990's and Beyond, ICE, London.

Jackson, H.B. and Bailey, R.A., 1978. Some Practical Aspects of River Regulation in England and Wales, J. Inst. Wat. Eng. Sci., River Engineering Section.

Johnson, P., 1988. River Regulation: A Regional Perspective. Northumbrian Water Authority. Regulated Rivers: Research and Management, Volume 2, 233-255.

Lack, P (1986). *The Atlas of Wintering Birds in Britain and Ireland.* British Trust for Ornithology, Irish Wildbird Conservancy.

Lambert, A. O., 1988. Regulation of the River Dee, Regulated Rivers: Research and Management, 2, 293-308.

Lee, N. and Wood, C., 1978. EIA - A European Perspective., Built Environment, 4(2).

Lee, N. and Walsh, F., 1992. Strategic Environmental Assessment: An Overview, Project Appraisal, 7(3).

Mann, R H K (1988). Fish and fisheries of regulated rivers in the UK. *Regulated rivers: Research and management*, Vol. 2.

Mann, R H K, Blackburn, J H and Beaumont, W R C (1989). The ecology of brown trout *Salmo trutta* in English chalk streams. *Freshwater Biology* Vol. 21.

Marchant, J H, Hudson, R, Carter, S P, and Whittington, P (1990). *Population Trends in British Breeding Birds*. BTO.

Mbumwae, L.L., 1986. Water Resource Management within the Zambezi River Basin, paper to Int. Symp. Impact of Large Water Projects on the Environment, UNESCO, Paris, France.

McDonald, A.T., and Kay, D. 1988. Water Resources Issues and Strategies. Longman Scientific & Technical, Harlow, England.

McIntosh, P. T., 1993. Water Resources Development: A Balanced Approach, J. IWEM, 7(4), 412-417.

Mermel, T.W., 1981. Major Dams of the World, Water Power Dam Const., 33(35).

Micklin, P P, 1978. Environmental Factors in Soviet Interbasin Water Transfer Policy. Environmental Management, Volume 2, No. 6, pp 567-580.

Millichamp, R I (1976). Some thoughts on water abstraction on migratory fish rivers. *Fisheries Management* Vol. 7.

Ministry of Agriculture, Fisheries and Food / National Water Council, 1976. The Fisheries Implications of Water Transfer Between Catchments, HMSO. London.

Mountford, O and Gomes, N 1991. Habitat preference of river water-crowfoot (Ranunculus fluitans Lam.) for application in PHABSIM testing. In Bullock, A, Gustard, A and Granger E S (1991). Instream Flow Requirements of Aquatic Ecology in Two British Rivers. Institute of Hydrology.

Mountford, O and Gomes, N 1990. Habitat preference of river water-crowfoot (Ranunculus fluitans Lam.) for application in PHABSIM testing. Unpublished Report to the Institute of Hydrology. In Bullock, A., Gustard, A. and Grainger, E. S., (1991), Instream Flow Requirements of Aquatic Ecology in Two British Rivers, Institute of Hydrology, Wallingford.

Mountford, O and Gomes, N (1991). *Habitat preference of river water-crowfoot* (Ranunculus fluitans Lam.) *for application in PHABSIM testing*. In Bullock, A, Gustard, A and Granger E S (1991). *Instream Flow Requirements of Aquatic Ecology in Two British Rivers*. Institute of Hydrology.

National Rivers Authority Severn Trent Region (Upper Severn Area). Strategic stock assessment programme, River Worfe. (Unpublished, June 1990).

National Rivers Authority-Thames Region, 1992. River Thames Strategic Flood Defence Initiative: the Datchet, Wraysbury, Staines and Chertsey Draft Floodplain Management Plan-Preliminary Environmental Assessment, NRA, Reading.

National Rivers Authority Severn Trent Region (Upper Severn Area). Assessment of fish stocks and distribution in the River Worfe. (Unpublished file note, E. North, 17.3.1986).

National Rivers Authority, 1992. Water Resources Development Strategy: A Discussion Document, National Rivers Authority.

National Rivers Authority, 1991. Demands and Resources of Water Undertakers in England and Wales: Preliminary Report Under Section 143(2)(a) Water Act 1989, National Rivers Authority.

National Rivers Authority, 1990. Corporate Plan, NRA, Bristol.

National Rivers Authority, 1989. Migration of Atlantic Salmon in the River Tywi, South Wales, paper presented to the Atlantic Salmon Trust Conference.

National Rivers Authority, 1991. Preliminary Results of the Environmental Impact of Liming Llyn Brianne, Internal Report, NRA Welsh Region.

National Rivers Authority, Anglian Region, 1993. Progress on Developing a Water Resources Strategy: A Presentation at Newmarket.

National Rivers Authority, Severn-Trent Region, 1992. Residual Flows to Estuaries 1992: A Review of the Current Situation and Guidance on Determination. Prepared for NRA Severn-Trent Region.

National Rivers Authority, Anglian Region, 1993. Water Resources Strategy: Consultation Draft.

Nature Conservancy Council (1988). *Shropshire Inventory of Ancient Woodland (provisional)*.

Nature Conservancy Council (1989). *Guidelines for selection of biological SSSIs.*

Nature Conservancy Council. National Vegetation Classification Scheme: swamps and tall-herb fens. (Unpublished, 198?)

Nature Conservancy Council. Otter survey of England 1984 - 1986.

Nelson, P.J., Corlett, J. and Swanwick, C., 1984. Environmental Impact Assessment Procedures used in a Strategic Study of Water Resource Development Options. In Roberts, R.D. and Roberts, T.M. (eds), Planning and Ecology, Chapman and Hall, London.

Nilsson, C, Ekblad, A, Gardfjell, M and Carlberg, B, 1991. Long-Term Effects of River Regulation on River Margin Vegetation, Journal of Applied Ecology, 28, 963-987.

North, E, 1980. 'The Effects of Water Temperature and Flow upon Angling Successes in the River Severn'. Fish. Mgmt. 11. 1-9.

NRA Severn-Trent Region (1991). *Objectives for Rivers and Canals*. NRA.

O'Riordan, T. and Hey, R., (eds.), 1976. Project Appraisal and Policy Review, John Wiley and Sons, Chichester.

OECD, 1989. Water Resource Management, Organisation for Economic Cooperation and Development, Paris.

OECD, 1991. Communique - an Environmental Strategy in the 1990's, Organisation for Economic Cooperation and Development,Paris, France.

OECD, 1987. Pricing of Water Services, Organisation for Economic Cooperation and Development, Paris.

OFWAT, 1990. Paying for Water - A Time for Decisions, Office of Water Services, Birmingham.

Orth, D.J. and Leonard, P.M. 1990. Comparison of discharge methods and habitat optimization for recommending instream flows to protect fish habitat. Regulated Rivers: Research and Management, Vol.1, pp 129-138.

Orth, D.J. and Leonard, P.M. 1990. Comparison of discharge methods and habitat optimization for recommending instream flows to protect fish habitat. Regulated Rivers: Research and Management, Vol.1, pp129-138.

Paradine, P.J., 1992. Sector Level and Regional Environmental Assessment, internal paper, World Bank, Washington, D.C.

Partidario, M. do R., 1992. An Environmental Assessment and Review Procedure. PhD Thesis, University of Aberdeen, Scotland.

Petts, G.E., 1989. Perspectives for Ecological Management of Rivers, in Gore, J.A. and Petts, G. E. (eds.), 1989. Alternatives in Regulated River Management, CRC Press, Florida.

Petts, G.E. and Armitage, P. 1991. The effects of abstractions from rivers on benthic macroinvertebrates. Loughborough University of Technology, Report to the Nature Conservancy Council.

Petts, G E, 1984. Impounded Rivers: Perspectives for Ecological Management, John Wiley and Sons, Chichester, 326pp.

Petts, G E (1988). Accumulation of fine sediment within substrate gravels along two regulated rivers, UK. *Regulated rivers: Research and management*, Vol 21.

Petts, G.E. and Armitage, P. 1991. The effects of abstractions from rivers on benthic macroinverebrates. Loughborough University of Technology, Report to the Nature Conservancy Council.

Phillips, R and Rix, M (1985). *Freshwater fish of Britain, Ireland and Europe.* Pan.

Pinfold, G., 1992. Strategic Environmental Assessment and Land-Use Planning, Project Appraisal, 7(3).

Planning, 1993. Clouds Gather over Water Strategy for Thirstiest Region, Planning, 3rd September.

Roy, D and Messier, D, 1989. A Review of the Effects of Water Transfers in La Grande Hydroelectric Complex (Quebec, Canada), Regulated Rivers: Research and Management, 4, 299-316.

Samuels, P G (1984). Computational modelling of Open Channel Flow - An analysis of some practical difficulties. Report IT 273. Hydraulics Research, Wallingford, UK.

Severn Trent Water Authority (1979). Groundwater Resource Assessment of the Triassic Sandstones.

Severn-Trent Water Authority (1989). *Water Quality 1988/89*: Appendix 6, River Quality - Biological.

Sewell, W.R.D. and Biswas, A.K., 1986. Implementing Environmentally Sound Management of Inland Waters, Resour. Policy, 12.

Sheail, J. 1982. Underground Water Abstraction: Indirect Effects of Urbanisation on the countryside. Jnl of Historical Geography, 8(4), pp 395-408.

Shiklomanov, I.A. 1985. Large scale water transfers in Rodda, J.C. (ed.), Facets of Hydrology, John Wiley & Sons, UK.

Shropshire Ornithological Society. Breeding bird atlas data, 1985-1991. (Due for publication March 1992.)

Sinker, C *et al* (1991) *Ecological Flora of the Shropshire Region.* Shropshire Wildlife Trust.

Smith, C.D., D.M. Harper and P.J. Barham, 1990. Engineering Options and Invertebrates: Linking Hydrology with Ecology, Regulated Rivers: Research & Management 5:89-96.

Solomon, D, 1975. Water Transfers and Coarse Fisheries, Proc. 7th Brit. Coarse Fish Conf., Liverpool, 14-22.

Solomon, D & Patterson, D, 1980. Influence of Natural and Regulated Streamflow on Survival of Brown Trout in a Chalkstream, Env. Biol. Fish. 5, 379-382.

Sonntag, N.C., Everitt, R.R., Rattie, L.P., Colnett, D.L., Wolf, C.P., Truett, J.C., Dorcey, A.H.J. and Holling, C.S., 1987. Cumulative Effects Assessment: A Context for Further Research and Development, CEARC, Hull, Quebec.

Swinnerton, C. J. and Sherriff, J. D. F., 1993. National Rivers Authority National Strategy and Planning for the Future, J. IWEM, 7(4), 404-411.

Tennant D L (1976). Instream flow regimens for fish, wildlife, recreation and related environmental resources. *American Fisheries Society*, Proceedings of the symposium and speciality conference on instream flow needs, Vol. 2.

Therivel, R., Wilson, E., Thompson, S., Heaney, D. and Pritchard, D., 1992. Strategic Environmental Assessment, Earthscan, London.

Therivel, R., 1991. Directory of Environmental Statements 1988-1991, School of Planning, Oxford Polytechnic, Oxford.

Turnbull, R., 1983. EIA, - The Relationship between the Environmental Scientist and the Decision Maker: A British Perspective, PADC, Aberdeen.

Tyler, S.J., 1992. Little Ringed Plovers in Wales in 1991, RSPB report for NRA.

Udall, S.L., 1963. The Quiet Crisis, Avon Books, New York.

UK Climate Change Impacts Review Group, 1991. The Potential Effects of Climate Change in the United Kingdom, HMSO, London.

UK Government, 1990. This Common Inheritance, - Britain's Environmental Strategy, Cm 1200, HMSO, London.

US Council on Environmental Quality, 1978. Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act, 40 CFR 1021.

US Department of Agriculture, 1990. Vegetation Management in the Ozark/Ouachita Mountains, Environmental Impact Report, Forest Service.

US Government, 1970. National Environmental Policy Act of 1969, 42 USC 4321-4347.

Vannote, R L, Minshall, G W, Cummins, K W, Sedell, J R and Cushing,áCáE, 1980. "The River Continuum Concept", Canadian Journal of Fisheries and Aquatic Science, 37, 130-137.

Verheem, R., 1992. Environmental Assessment at the Strategic Level in the Netherlands, Project Appraisal, 7(3).

Walsh, P.D., Walker, S. and Pearson, D., 1988. Derivation of Operating Policies for Surface Water Sources in North West Water, J.IWEM, 2(1).

Warn, A E, 1990. Environmental Impact Assessment. The Approach of the National Rivers Authority. Unpub. Paper Presented at a Seminar on Environmental Impact Assessment, the Implications for the Water Industry, Churchill College, Cambridge, 27 March.

Water Resources Board, 1970. Water Resources in the North, HMSO.

Water Resources Board, 1966. Water Resources in South East England, 2 vols, HMSO.

Water Resources Board, 1973. Water Resources in England and Wales,

Water Resources Board, 1971. Water Resources in Wales and the Midlands, HMSO.

Water Services Association, 1990. Water Facts, 1990, London.

Water Resources Board, 1972. Desalination for Drinking Water Supplies, HMSO.

Water Research Centre, 1990. National Metering Trials, Second Interim Report, WRC, Medmenham.

Wathern, P., 1976. The role of Impact Statements in Environmental Planning in Britain, International Journal of Environmental Studies, 9.

Wathern, P., Young, S.N., Brown, I.W. and Roberts, D.A., 1987. Assessing the Impacts of Policy: A Framework and an Application, Landscape and Urban Planning, 14.

Wathern, P., Brown, I., Roberts, D. and Young, S., 1988. Assessing the Environmental Impacts of Policy, in Clark, M. and Herington, J. (eds.), The Role of EIA in the Planning Process, Mansell, London.

Wathern,P. (ed.), 1988. Environmental Impact Assessment: Theory and Practice, Routledge, London.

Watson, D (1987). Hydraulic effects of aquatic weeds in UK rivers. *Regulated Rivers: Research and Management*, Vol. 1, 211-227.

Webb J. W. and Sigal, L. L., 1992. Strategic Environmental Assessment in the United States, Project Appraisal, 7(3).

Webb, B W and Walling, D E, 1993. "Temporal Variability in the Impact of River Regulation on Thermal Regime and some Biological Implications", Freshwater Biology, 29, 167-182.

Welsh Water Authority, 1987. General Directions for Regulation of the River Dee. Weston, A. E., 1987. Hydrology in the Incident Room, 1st National Hydrology Symposium, Hull.

Welsh Water Authority, 1988. The Water Quality of Llyn Brianne and Effects of Regulation Releases on the River Tywi, Internal Report.

Welsh Water Authority, 1986. A Survey of Juvenile Salmonid Populations in the Tywi River System. Internal Report.

Wood, T.R. 1981. River management In British Rivers (J Lewin - Ed). George Allen & Unwin, London.

Wood, C., 1990. The Environmental Assessment of Policies, Plans and Programmes, Environmental Policy and Management: an International Forum, The British Council/CEMP, Alfriston.

Wood,C. and Djeddour, M., 1992. Strategic Environmental Assessment: EA of Policies, Plans and Programmes, Impact Assessment Bulletin, 10(1).

World Commission on Environment and Development (Brundtland Commission), 1987. Our Common Future, Oxford University Press, Oxford.

World Bank, 1991. Environmental Assessment Sourcebook, Volume 1 - Policies, Procedures and Cross Sectoral Issues, Technical Paper 139, Environment Department, World Bank, Washington D.C.

World Bank, 1989. Operational Directive 4.00 on Environmental Assessment, Environment Department, World Bank, Washington D.C. (Revised 1991, OD 4.01).

World Bank, 1990. Dams and the Environment: Considerations in World Bank Projects, Tech. Paper No. 110, World Bank, Washington D.C.

Wright, J.F., Blackburn, J., Westlake, D.F., Furse, M.T. and Armitage, P.D., 1992. Anticipating the Consequences of River Management for the Conservation of Macroinvertebrates, in Boon, P.J., Callow, P. and Petts, G.E., (eds.) River Conservation and Management, John Wiley and Sons, Chichester.

APPENDIX F

Summary Sheets for UK Schemes

SUMMARY OF KIELDER REGULATION AND TRANSFER SCHEME

Objectives of scheme:

The main purpose of the Kielder scheme was to guarantee regional water supplies for domestic and industrial purposes. The reservoir regulates the rivers North Tyne and Tyne but the scheme has the capacity to transfer water south, via pipeline, from the river Tyne at Riding Mill to the river Wear at Frosterly and the river Tees at Egglestone. As the actual need for transfers has been much less frequent than originally forecasts, regulation releases for Hydro Electric Power generation are now a major component of the scheme.

Date of implementation:

The engineering scheme was completed in 1980, with Kielder reservoir filling for the first time in 1982.

Physical components of the scheme:

Kielder Reservoir

* Catchment area:	241km2
* Capacity:	200,000Ml
* Yield:	900Mld
* Compensation flow:	114Mld
* Maximum release:	60 cumecs (5184Mld)

Transfer Tunnel

* Tunnel length	33km
* Wear regulation capacity	300Mld
* Tees regulation capacity	270Mld (3 pumps at Riding Mill)

Frequency of operation:

Prior to May 1993, regulation release were made for Hydro Electric Power generation virtually every day (except during dry summer periods). The HEP releases involved an increase in flow from 1.32 cumecs compensation to a peak generating flow of 16.4 cumecs for a period of around 6 hours. A new regime is now being operated to minimize adverse impacts of such an unnatural regime, this involves making continuous releases over 3 days per week at a discharge of 10.3 to 16.4 cumecs.

The transfer tunnel has been used mainly to regulate the River Wear during the dry summers (1989-1992). The River Wear is subject to a Minimum Maintained Flow of 2 cumecs at Chester-le-Street and transfers have been necessary to prevent violation. These regulation releases account for over 50% of the flow close to the release point and around 30% of the flow at Chester-le-Street during low summer flows.

Releases into the River Tees have been much less common as Cow Green reservoir and the Lune/Balder group provide a greater capacity for regulation than is available on the River Wear. Consequently transfers were only made in 1989 and for a couple of days in 1990.

Hydrological Impacts

Regulation Impacts on the River Tyne

	Pre-Kielder		Post-Kielder	
	Q95	Mean Daily Flow	Q95	Mean daily Flow
Reaverhill	2.0	19.9	3.0	20.8
Bywell	5.2	43.6	7.3	47.3

Low flows on the North Tyne have been substantially increased as a result of Kielder. The impact of flood flows is more difficult to assess, though flood peak reduction at Tarset 10km downstream from the dam has been estimated at 50%.

Perceived and measured impacts

Measured impacts

* Reduced diversity and abundance of macroinvertebrates on the North Tyne immediately downstream of Kielder.

* Reduced salmonid populations immediately downstream of the Dam.

* Precipitation of organic compounds (up to 2cm thick), rich in Fe, Al and Mn, on sediments immediately downstream of the Dam (may account for invertebrate and Salmonid impacts).

* Compaction of gravels due to HEP releases and lack of natural floods.

* Marked increases in flow velocities on the rising limb of HEP releases.

* Moderated temperature regime (higher in winter and lower in summer) downstream of the dam.

Perceived impacts

* Reduced Coarse fish populations downstream (eg Dace).

References

NUMEROUS INCLUDING:

Petts G E, Foulger T R, Gilvear D J, Pratts J D and Thoms M C (1985): Wave movement and water quality variations during a controlled release from Kielder reservoir. J of Hydrology, 80, 371 - 389.

Sear D A (1992): Impact of Hydroelectric Power Releases on Sediment Transport processes in pool - riffle sequences IN Dynamics of Gravel-bed Rivers ed Billi, Hey Thorne and Tacconi.

Haile S M, James A, and Sear D (1989): The effects of Kielder reservoir on the ecology of the River North Tyne. Report for Northumbrian Water Authority.

Sear D A (1992): Sediment transport processes in riffle pool sequences and the effects of river regulation for hydro electric power within the North Tyne. Unpub Phd thesis.

Johnson P (1988): River regulation: a regional perspective - Northumbrian Water Authority IN Regulated Rivers: research and management, vol 2, 233 - 255.

SCHEME SUMMARY SHEETS

COW GREEN REGULATION SCHEME

Objectives of scheme:

To support abstractions at Broken Scar and Blackwell for domestic consumption and provide industrial supplies on Teesside. Purely for river regulation. Enabled the MMF to rise from 45.5Mld to 127.3Mld.

Date of implementation:

Completed in 1971.

Physical components of scheme:

Grid reference: NY 812290
Reservoir capacity: 40 915 Ml
Catchment area: 58.9 km2
Compensation water: 38.6 Mld
Maximum release: 600 Mld (when full)
Travel time to main abstractions: 24 to 38 hours

Frequency of operation:

Used virtually every day. Flood storage releases are made from November to March of up to 550 Mld and support for abstractions, on average 250 Mld, is generally made from April to October. Releases can be altered every eight hours so that the arrival of the water corresponds to the night time pumping at the three abstraction points. Regulation releases from Cow Green can be very high and in dry periods the whole length of the River Tees benefits from substantial amounts of river regulation.

With/without hydrology: (values in cumecs)

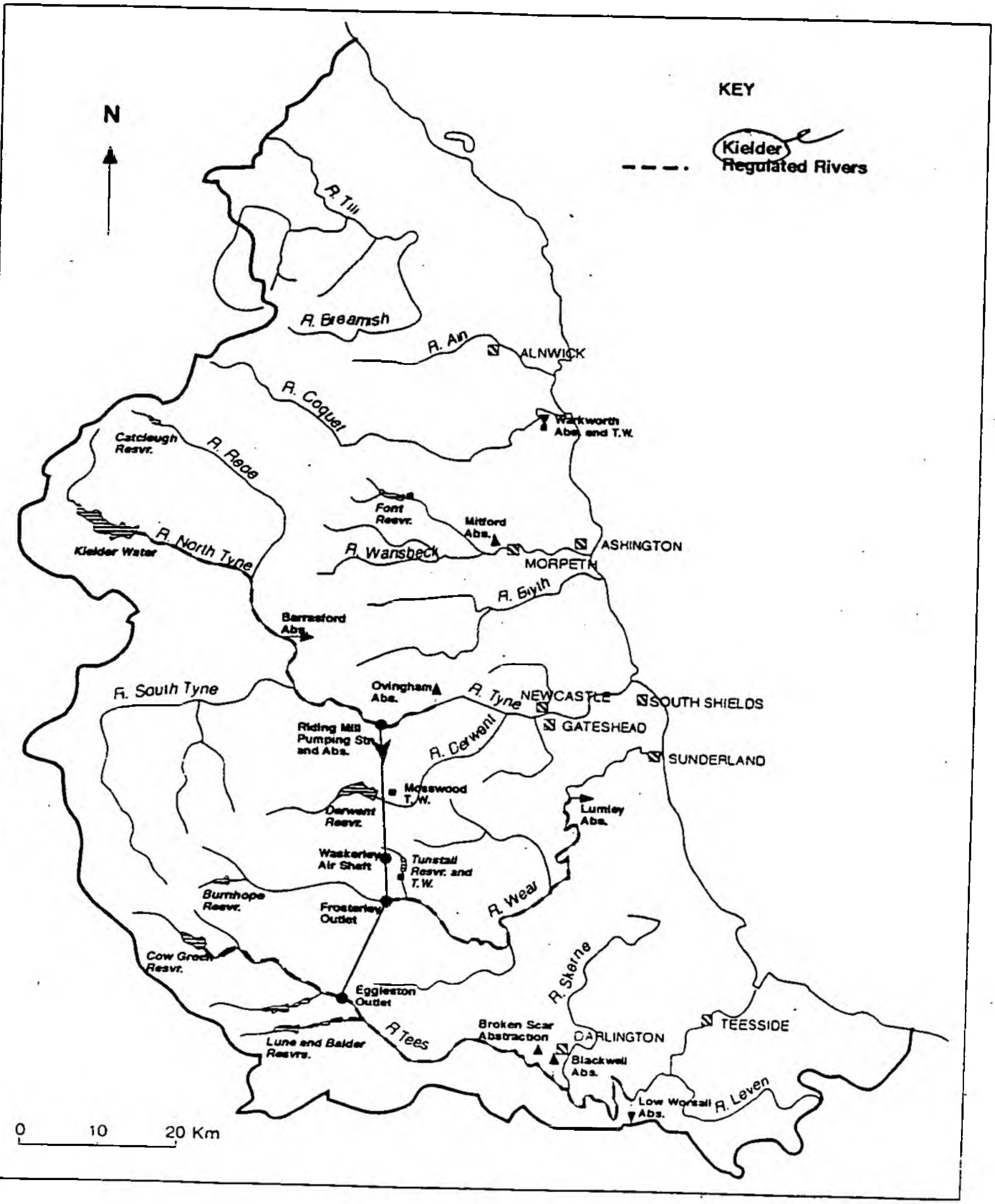
	Pre 1971			Post 1971		
	Q10	Q50	Q95	Q10	Q50	Q95
Dent Bank (1956 - 1974)	19.5	3.2	.56	19.4	4.2	2.0
Barnard Castle (1966 -)	36.4	7.6	2.4	29.0	7.3	4.0

Perceived/measured impacts:

Geomorphology: none.

Physical impacts: Barnard Castle: pre 1971 max flow = 513 cumecs, post 1971 = 269 cumecs. Dent Bank: pre 1971 max flow = 446 cumecs (top 38 flows are pre 1971), post 1971 = 206 cumecs (only 3 flows in top 63 are post Cow Green).

Water quality: mean annual potassium loadings have been reduced to 60% of normal and


KEY
Kielder
Regulated Rivers
N
R. Till
R. Breamish
R. Aln
ALNWICK
R. Coquet
Warkworth Abs. and T.W.
Catcleugh Resvr.
R. Rede
Font Resvr.
Mitford Abs.
ASHINGTON
Kielder Water
R. North Tyne
R. Wansbeck
MORPETH
R. Blyth
Barrasford Abs.
R. South Tyne
Ovingham Abs.
R. Tyne
NEWCASTLE
SOUTH SHIELDS
GATESHEAD
Riding Mill Pumping Stn. and Abs.
R. Derwent
SUNDERLAND
Mosswood T.W.
Derwent Resvr.
Lumley Abs.
Waskerley Air Shaft
Tunstall Resvr. and T.W.
Burnhope Resvr.
Frosterley Outlet
R. Wear
Cow Green Resvr.
R. Skerne
Eggleston Outlet
R. Tees
Broken Scar Abstraction
DARLINGTON
TEESSIDE
Lune and Balder Resvrs.
Blackwell Abs.
Low Worsall Abs.
R. Leven
0
10
20 Km

CLYWEDOG RESERVOIR - SCHEME SUMMARY

Objectives - Clywedog Reservoir was designed specifically to augment flows in the River Severn during low flows and operates as part of the River Severn Water Resources/Supply system together with the Shropshire Groundwater Scheme and Vyrnwy Reservoir.

Date of Implementation - Commissioned in 1967.

Physical Components of Scheme - The reservoir provides storage of 50,000 Ml derived from a natural catchment in the Welsh uplands and is operated by Severn Trent Water under a Section 20 agreement. Releases are made to the River Severn via the Afon Clywedog. In addition to regulation, releases are also made for hydropower generation under suitable conditions.

Frequency of Operation - Discharges are made from the reservoir during low flows to ensure that the average flow in the River Severn at Bewdley in any period of five consecutive days is not less than 850 Ml/d, subject to a maximum release from Clywedog Reservoir of 500 Ml/d.

Perceived/Measured Impacts

- Hydropower generation is a benefit of this scheme.
- Contributes to flood alleviation.
- Flows lower and therefore temperatures higher leading to some increase in eutrophication in the lower reaches of the regulated river.
- Introduces water of good quality thus changing water character on mixing with receiving water downstream.
- Changes in temperature.
- Reduced dissolved oxygen levels have been experienced in the past (now resolved).
- Increased recreation activities (water sports, angling).
- The changed flow profile caused by regulation reduces the periods during which reaches of the River Severn are navigable.
- Impacts associated with construction of scheme.
- Rapid changes in flow/level may have adverse impact on aquatic life on Afon Clywedog.

VYRNWY RESERVOIR - SCHEME SUMMARY

Objectives - Vyrnwy Reservoir was designed to supply Liverpool but also operates in a minor role as part of the River Severn Water Resources/Supply system together with the Shropshire Groundwater Scheme and Clywedog Reservoir.

Date of Implementation - Lake Vyrnwy has supplied Liverpool directly since 1891.

Physical Components of Scheme - The reservoir located in the Welsh uplands provides storage of 59,700 Ml and provides a direct supply of up to 208 Ml/d to North West.

A "water-bank" system is employed so that a proportion of storage can be used to regulate the flow of the River Severn.

Flood drawdown releases 405 Ml/d.

Typical regulation release including compensation of 45 Ml/d is c 8 0 Ml/d.

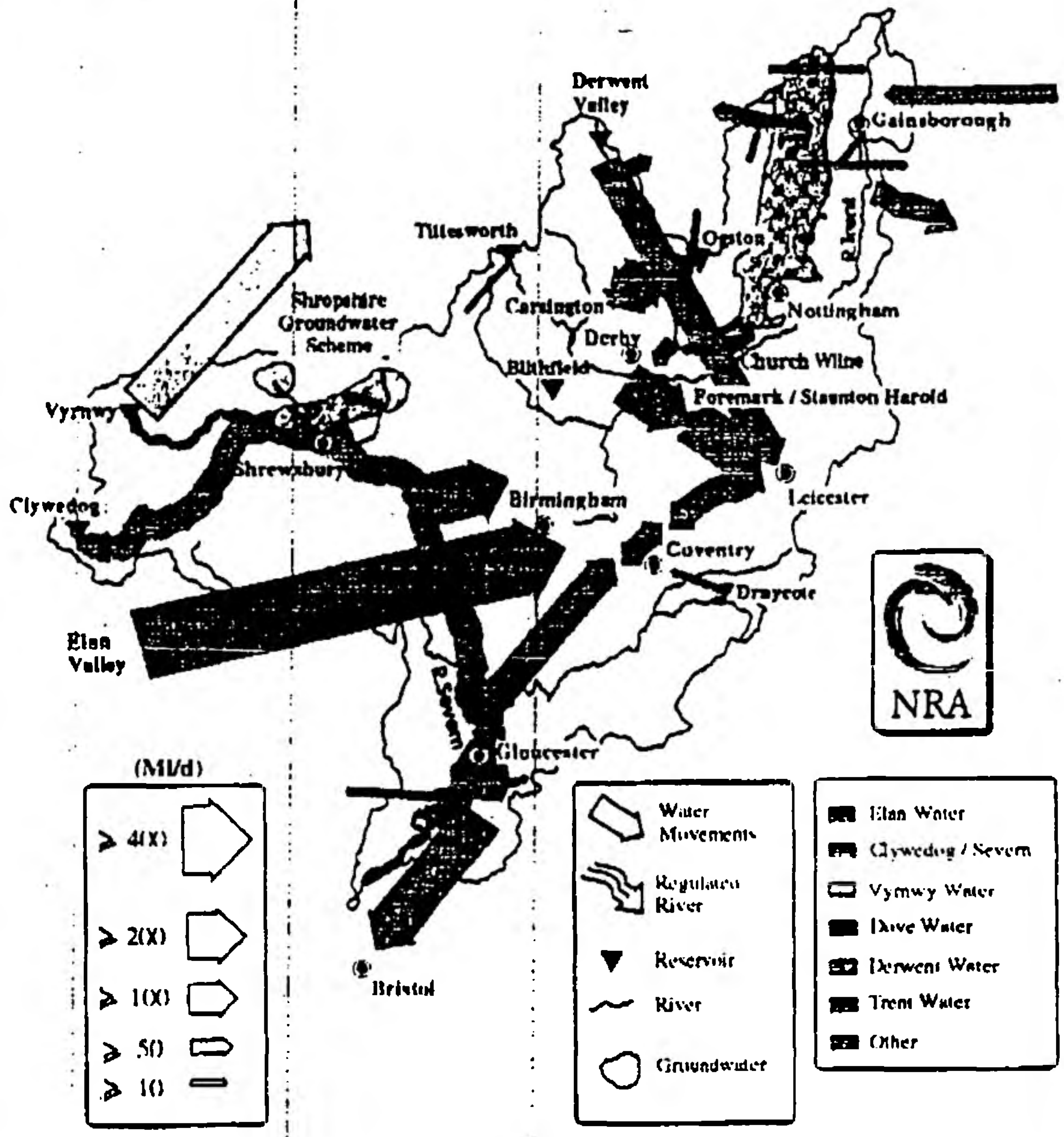
Compensation releases of up to 45 Ml/d are made via the River Vyrnwy into the River Severn. The scheme is operated under a Section 20 Agreement by Severn Trent Water.

Frequency of Operation - Use for river regulation is variable, in drought years eg 1975, 1976, 1984, 1989, 1990 would be used for 80 to 120 days.

Perceived/Measured Impacts

- Variation in flows and temp changes.
- Recreation on reservoir and canoeing when large releases are made.

Figure A.1: Regional Public Water Supply Network



CARSINGTON RESERVOIR - SCHEME SUMMARY

Objectives - The scheme forms part of Severn Trent Water's supply strategy for meeting demands for water in the East Midlands into the next century.

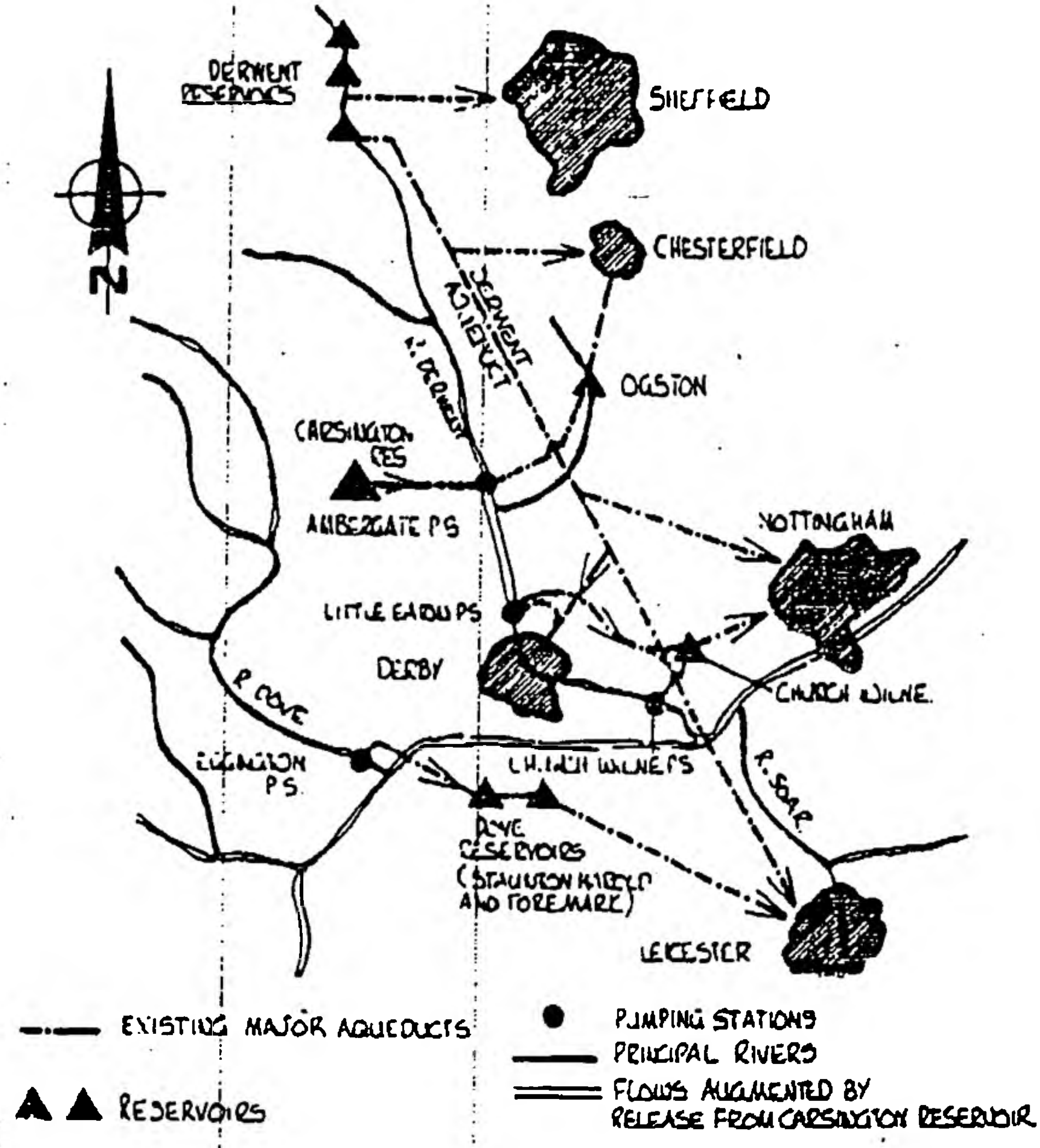
Date of Implementation - Opened summer 1992.

Physical Components of Scheme - The reservoir scheme consists of a pumped storage reservoir of 35,000 Ml capacity situated on the Scow (or Henmore) Brook, a tributary of the River Dove between Wirksworth and Ashbourne in Derbyshire. The reservoir has a small natural catchment (13 km^2), with all significant inflow pumped from the River Derwent, at Ambergate, at times of high river flow. Water stored in the reservoir may then be released back to the River Derwent at Ambergate to support abstractions from the lower Derwent. Water may also be transferred via Ambergate to Ogston Reservoir.

Frequency of Operation - This scheme will be utilised during summer months to augment flows in the River Derwent, which in turn supports public water supply abstractions for the East Midlands supply system. The use of this resource is planned to increase to meet increased supply demands in the future.

Perceived/Measured Impacts

- Altered dissolved oxygen and temperature regime.
- Increased recreation activities associated with reservoir (water sports, angling).
- Visual impact and increased influx of visitors to reservoir site.
- Impacts associated with construction of scheme eg acid runoff which required neutralisation before discharge to Henmore Brook.



THE CARSINGTON RESERVOIR SCHEME
(after Davey and Eccles)

SEVERN TR

SHROPSHIRE GROUNDWATER - SCHEME SUMMARY

Objectives - The Shropshire Groundwater Scheme is a phased development designed to augment flows to the River Severn in drought years as part of the River Severn Water Resources/Supply system. The River Severn is a major water resource for public supplies within the region and to Bristol as well as meeting the needs of agriculture and industry. During low flows the River Severn is boosted primarily by releases from Clywedog Reservoir and only in drought years is water pumped from the groundwater in Shropshire to maintain Severn flows.

Date of Implementation - Two phases out of a planned eight have currently been implemented. Phase I was fully operational in 1984, and phase II in 1992.

Physical Components of Scheme - The overall scheme consists of eight stages, each comprising boreholes linked by pipelines to the River Severn or its tributaries. Water pumped from the boreholes is used in this way to augment River Severn flow.

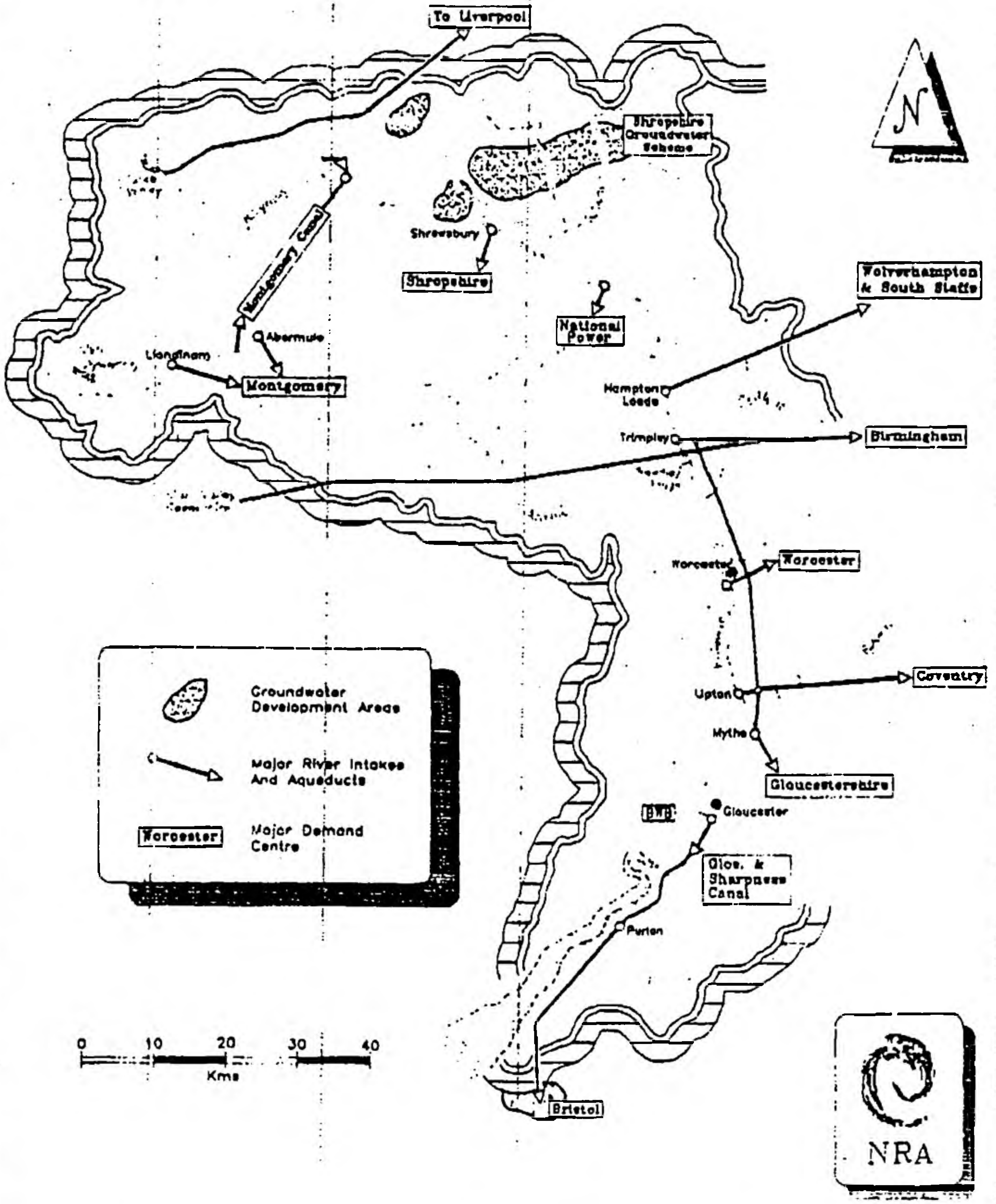
The total gross yield when the scheme is fully commissioned will be 330 Ml/d equivalent to 235 net. Yield from phases I and II is of the order of 105 Ml/d gross (80 Ml/d net).

Frequency of Operation - The normal mode of operation is to use Clywedog Reservoir during the first days and weeks of a drought. When Clywedog has insufficient water in store to meet the subsequent augmentation requirements in a severe drought boreholes in the Shropshire Groundwater Scheme will be brought into operation. Phase I has been used in 1984 and 1989. Phase II was extensively test pumped in 1991/92 but has not yet been required for operational purposes.

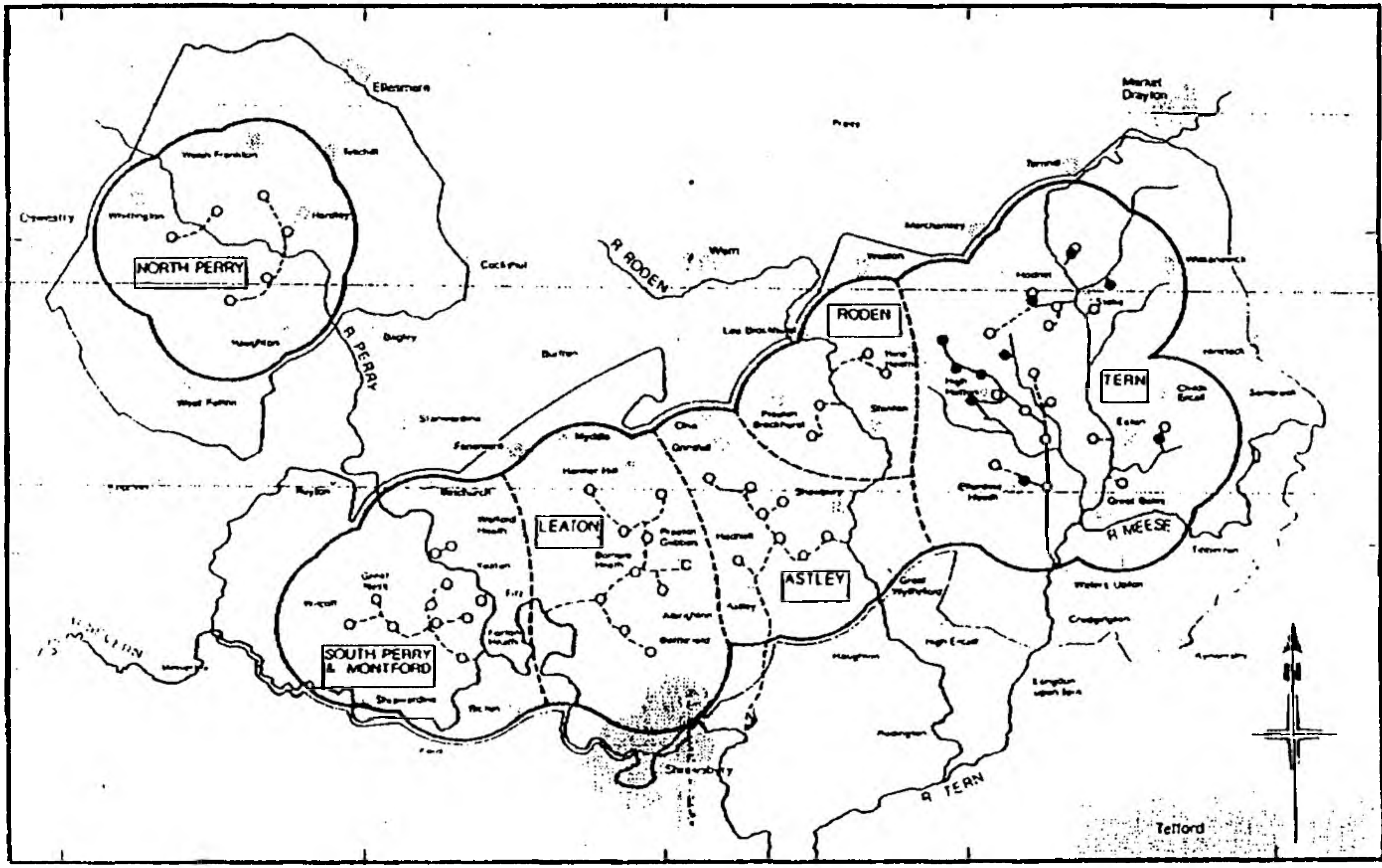
Perceived/Measured Impacts

- Some decline in groundwater levels and soil moisture levels at pumping sites where the water table is shallow anyway. A thorough environmental monitoring programme forms part of the scheme to identify any problems.
- Low levels of dissolved oxygen in the pumped groundwater are a concern. In practice this problem is simply solved by use of an aerator.
- Lower temperature of pumped groundwater (10°C) being added to surface water (at 15 - 20°C).
- Increased iron/manganese concentrations which can coat the stream bed and have adverse implications for downstream abstractions.
- Increased chloride levels, affecting water character and restricting use for spray irrigation.
- Reduced water temperatures suppress fish growth and reproduction.
- Regulation affects residual flows to the estuary and hence salmon migration to the estuary and upstream.
- Nitrogen gas from groundwater can give fish a version of the bends.
- Impacts associated with construction of scheme.

The River Severn Water Resources/Supply System



THE SHROPSHIRE GROUNDWATER SCHEME - ABSTRACTION BOREHOLES AND SEQUENCE OF STAGES. Fig. 5



Development area, Inner protected area } under terms of
Outer protected area } STWA/NFU/CLA agreement

TERN Location of stage

Tern I abstraction boreholes & pipelines
Later stage abstraction boreholes & pipelines

Sequence of stages
1 Tern I
2 South Perry & Montford
3 Leaton
4 Tern II
5 Astley
6 Roden
7 North Perry
8 Tern III

Kilometres 0 1 2 3 4 5 6 7 8 9 10

Other Schemes

SUMMARY OF PERCEIVED AND MEASURED IMPACTS ON RIVERS DOWNSTREAM OF THE ELAN AND USK RESERVOIRS

N RESERVOIRS

Geomorphology - No recorded impact. (Ron Clark - Monmouth)

oding - Only problem occurs if the reservoirs are emptied(Ron Clark- Monmouth)

er Quality - Some unrecorded evidence that the impoundment has affected the temperature,DO and pH regime of the river d/s of the dam particularly at times of impoundment overspill. The water quality staff at Monmouth are about to start looking at the effects in more detail.
May have had an effect of increasing the amount of iron and manganese ions.(Paull 1978-unpublished MSc Thesis on Benthic Inverts and deposits in the R Elan) Mean concentrations of 0.5 Fe and 0.1Mn mg/l in the river Elan. This was 10 times the results in the upper Wye. Complicated by water treament works effluent and acidification problems also in the area. Upper Wye Catchment Management Plan 1993 - says the water quality may be effected by the impoundment.

vigation/Recreation and Amenity - No recorded impacts. But knock-on effect of influencing angling success. General inconvenience of alterations in flow.

Aquatic Ecology - Ref The effects of Impoundment on the downstream Macroinvertebrate Riffle Fauna of the River Elan - R.J.Inverarity, G.D.Rosehill and M.P.Brooker 1983 pointed out that macroinverts pops in R.Elan d/s of reservoir were less diverse as compared to those in the river Wye. Could have been due to elevated iron and manganese (including deposition of iron and manganese salts on the substrate), reduced pH, reduced temperature or increased invertebrate drift due to high/fluctuating flows. All of which could have been caused by impoundment. Difficult to differentiate the effects of regulation from those of acidification in this catchment. Also see Caban Goch Reports.

Conservation/Terrestrial Ecology - No recorded impacts although it is necessarily a change in ecology from what was there before the reservoir was constructed. Changes in riverflow also affect riparian communities when there is an increase in the depth of the water.

Fisheries - Fish population immediately d/s of dam is very poor with only a few brown trout and pike present. Fish pop improves further downstream.
Temperature regime can be seen to affect the growth of juvenile salmon and trout but no formal report to show this. Could affect fry emergence and survival. Smolt migration is also affected by temperature and flow.
Large variations in flow cause unstable habitat for fish reproduction and may even lead to stranding of juveniles when wetted area of river bed is significantly reduced by impoundment. No direct evidence for this in the Elan.
Of course a large spawning area was lost in the creation of the reservoir.
Possible effect of various metals in the water restricts improvement in fisheries in the river Elan.

The altered flow regime must also necessarily have an effect on the fish population by inhibiting feeding activity and cause loss of food organisms due to invertebrate drift.

USK RESERVOIR

Geomorphology/Physical Impacts - No effect shown

Water Quality - Only proper survey done was during drought to look at DO in Usk d/s of reservoir. Other problems envisaged include change in temperature and pH.

Nav/Rec/Amenity - No recorded effects

Aquatic Ecology - No data to show a problem. As from this year we are monitoring the biology up and downstream of the reservoir so will be able to conclude something from this. Must have some effect on Biology due changes in flow regime, temperature etc. as in the Elan.

Fisheries - ?.

SYNOPSIS. The South East Wales Conjunctive Resources Group, comprising water resources, water treatment and fishery staff from the National Rivers Authority and Welsh Water, was established to optimise the combined use of the water resources serving south east Wales. This paper identifies the current resources and briefly considers the historical operation of the sources and the changes instigated following the droughts of 1976 and 1984. More recent changes, particularly to the regulation of the River Usk, are discussed.

DESCRIPTION OF SOUTH EAST WALES CONJUNCTIVE RESOURCE SYSTEM

1. The South East Wales Conjunctive Resource area is approximately 2400 sq km and affords a supply of 502 Ml/d to a population of 1.25 million people concentrated in the conurbations of Newport and Cardiff and the industrial valleys of Gwent and Glamorgan and the Usk valley. The resources available to meet this demand are shown schematically in Figure 1.

OPERATION BEFORE 1976

2. Prior to 1976, the available water resources comprised:

a) Six upland direct supply reservoirs located in the Heads of the Valleys area (roughly mid-way between Cardiff and Brecon) and constructed between 1884 and 1939. These are, from west to east, the Taf Fawr group (Beacons, Cantref and Llwynon reservoirs), the Taf Fechan group (Upper Neuadd and Pontsticill reservoirs) and Talybont.

b) Usk reservoir, situated in the headwaters of the River Usk near Trecastle used for both direct supply to Swansea valley and regulation of the River Usk.

c) A pumped storage reservoir at Llandegfedd, near Pontypool, relying on abstraction from the River Usk at Rhadyr near to the tidal limit.

d) An abstraction from the River Usk at Llantrisant, near to the tidal limit.

e) A number of springs and small reservoirs collectively known as the Minor Sources mostly located in the Heads of the Valleys area near Merthyr Tydfil.

3. The raw water from these sources was supplied to a number of major treatment works. There were two works for the Taf Fawr sources (Cantref and Llwynon), two works for the Taf Fechan sources (Neuadd and Pontsticill), a separate works at Talybont, and two works (Sluvad and Court Farm) which are effectively one unit and were associated with Llandegfedd and the River Usk abstractions at Rhadyr and Llantrisant.

4. There were two other upland sources in the area, but neither were available for water supply purposes in south east Wales:

a) The Elan Valley reservoir complex in mid-Wales provided direct gravity supply to Birmingham and had a minor river regulation role on the River Wye.

b) Cray Reservoir, situated near Usk reservoir, which provided a direct supply to the upper Swansea valley.

5. Each of the above reservoirs was constructed to provide direct supply to a specific demand area. There was minimal provision for the transfer of water between sources and demand areas. The demand areas for each source and the usable storage is detailed below:

Source	Storage (Ml)	Original Demand Centre
Talybont	10,340	Newport
Taf Fawr	7,869	Cardiff
Llandegfedd	23,650	Cardiff
Taf Fechan	15,913	Rhymney and Taff valleys and Llantrisant
Elan	99,106	Birmingham
Usk	11,990	Swansea Valley
Cray	4,204	Swansea Valley

6. The lack of any real flexibility led to major problems in 1976. Some sources were virtually empty whilst others were not. Most of Cardiff and Merthyr Tydfil were subject to 18 hour supply rota cuts and supplies were only maintained by obtaining drought orders to permit abstraction from the River Usk, further depleting the already low flows. However, Newport's supplies were not interrupted.

SYSTEM CHANGES 1976 - 1989

7. Following the drought of 1976, Welsh Water Authority made substantial investment to increase both the resources available to south east Wales and the flexibility of their use. Initially progress was made by developing the embryonic River Wye Regulation Scheme for water supply purposes. This started in 1985 by redeploying the Elan Valley reservoirs compensation water and licensing an associated abstraction from the River Wye at Monmouth. This abstraction is pumped

to Court Farm in the lower Usk catchment for treatment. In addition, powers were obtained to use Cray reservoir for regulation purposes to support the Rhadyr abstraction to Llandegfedd.

8. Operational yields were derived for each of the reservoirs and the regulation systems using the methods discussed in Reference 1.

9. Extensive analysis of inflow data for each of these sources has shown that the majority are single season critical with the exception of Usk Reservoir. Taf Fechan and Talybont reservoirs are borderline.

10. The Conjunctive Resource area can be subdivided into a number of demand centres which are listed below together with their current demand values:

Cardiff Demand Centre	223 Ml/d
Talybont Demand Centre	62 Ml/d
Taf Fechan Demand Centre	120 Ml/d
Minor Sources Demand Centre	23 Ml/d
British Steel (Llanwern)	74 Ml/d
Total	502 Ml/d

11. The total demand of 502 Ml/d is matched by an operational yield of 510 Ml/d. Overall, there are just sufficient resources to meet the demands under drought conditions.

12. In the Heads of the Valleys area, the small, elevated Minor Sources have a particular problem - their output has to be reduced early in drought conditions to maintain certain minimum supplies. Operationally, this shortfall can only be met from the Taf Fechan reservoirs which are already unable to satisfy their demand area fully. The solution has come from the additional resource from the regulated River Wye via Court Farm which is now able to supply the Cardiff and British Steel demand centres. This in turn allows resources in the Taf Fawr reservoirs to be redeployed to support the Taf Fechan sources up to a maximum of 42 Ml/d. An extra 10 Ml/d can be supplied into the Taf Fechan demand centre from south west Wales (originating from Llyn Brianne reservoir) via the Pyle Transfer together with a further [illegible] Ml/d from Sluvad and Court Farm by pumping up the Taff valley at Cilfynydd.

13. This has required construction of a number of interconnections, small pumping stations, and a large increase in treatment capacity at Court Farm. Additional minor interconnections allow Sluvad/Court Farm water to support certain parts of the Talybont supply area.

OPERATIONAL MANAGEMENT DEVELOPMENTS AFTER 1989

14. Since the droughts of 1989 and 1990, the emphasis has

been on refining the operation of the existing resources to maximise their use, rather than on major engineering capital investment. The small surplus of yield over demand requires careful management of the resources to minimise the risk of supply failure and the need to apply for drought orders. This requires particular care early in the year to ensure that the upland, direct supply sources are not overdrawn too soon. Security of supply only exists if there is sufficient water retained in Taf Fawr to support Taf Fechan. This in turn requires Llandegfedd to replace the Taf Fawr water normally provided to the Cardiff demand centre.

15. Operational control rules have been agreed by the Group. The underlying premise of the control rules is that the system is operated to maximise resource and supply security during times of drought or when a resource shortfall threatens rather than to minimise costs.

OPERATIONAL CONTROL RULES

16. As an example of the control rules used, this section examines the operation of the Cray, Usk and Llandegfedd Reservoirs - the River Usk Regulation Scheme.

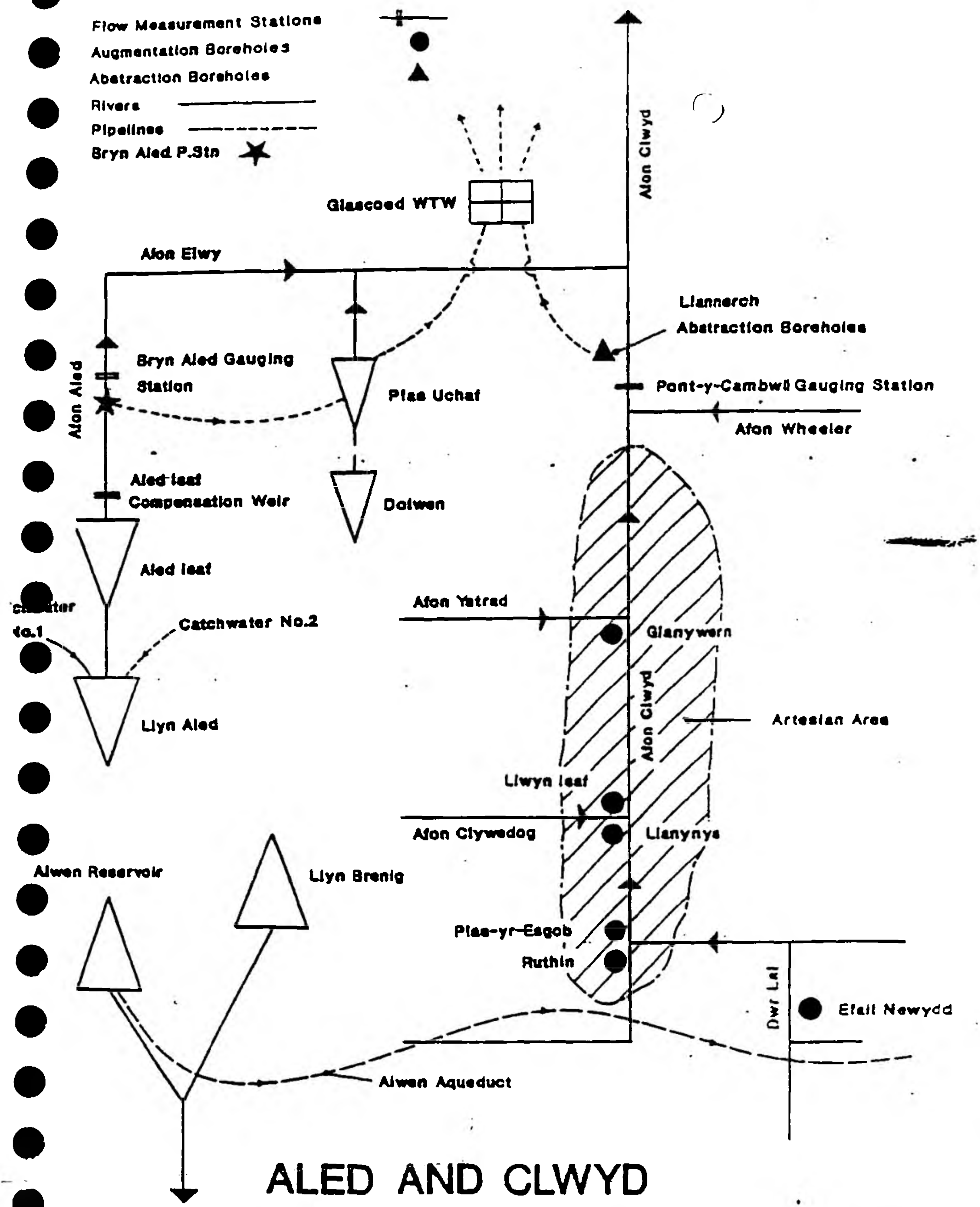
17. Prior to 1991, the Rhadyr abstraction had two main conditions. Firstly, below a particular river flow, water had to be released from Usk Reservoir to match the abstraction on a 'put and take' basis. Secondly, releases had to be made to the river to leave a minimum river flow of 227 Ml/d below the abstraction point. Under such conditions resources should have been 'donated' to the river which then could not be abstracted. In practice, this never happened.

18. In practice during the 1976 and 1984 droughts, the regulation water was held in Usk Reservoir until late in the drought. By that time, the river flows had recessed to the point where the maintained flow condition came into force. Since overall resources were depleted, drought orders were obtained to remove the maintained flow condition and the less stringent 'put and take' condition prevailed. Once the regulation storage was exhausted, further drought orders were obtained authorising abstraction from the natural flow.

19. During the 1989 and 1990 droughts, drought orders were avoided by transferring Usk Reservoir storage to Llandegfedd early in the season and therefore before the maintained flow condition became effective.

20. Whilst avoiding drought orders and fully using the [illegible] Reservoir resource, the early season transfer does [illegible] drawbacks. Usk Reservoir has poor refill cha[illegible] Drawing down the reservoir early in the sum[illegible] unnecessary, and could result in the reservoir not being [illegible] at the start of the next summer and compromise its operation in that second year. In addition, the direct supply [illegible] Swansea Valley would be restricted to the minimum [illegible] throughout the summer and possibly the follo[illegible] These problems have been overcome by the agreed [illegible]

Sketch of System



ALED AND CLWYD REGULATION SCHEMES

Figure 1

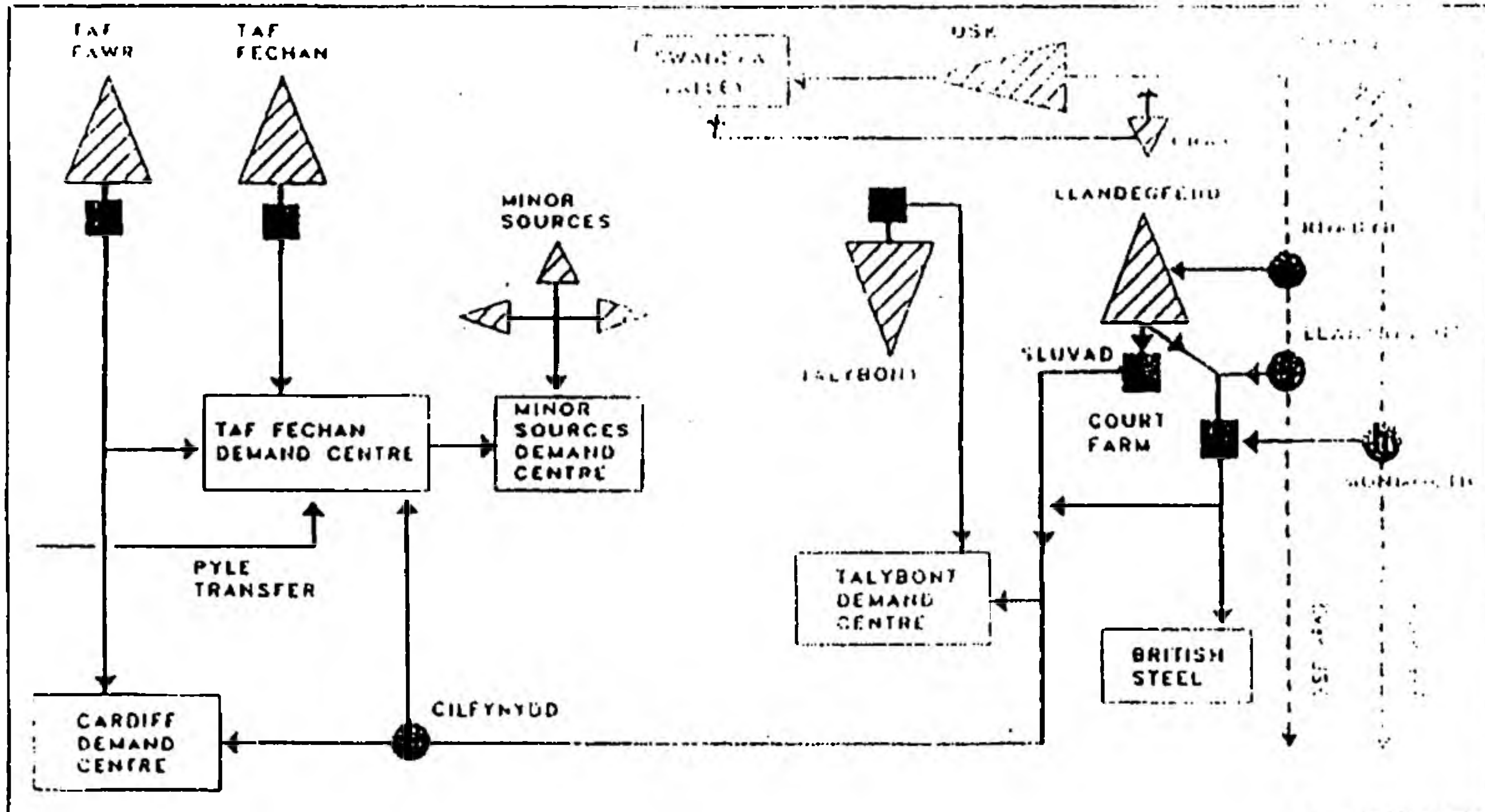


Figure 1: SCHEMATIC OF SE WALES CONJUNCTIVE RESOURCE SCHEME

KEY: TREATMENT WORKS; SOURCE; PUMPING STATION; DEMAND CENTRE; REGULATED RIVER

FIGURE 2. USK REGULATION
AGGREGATED STORAGE

KEY: A
B
C

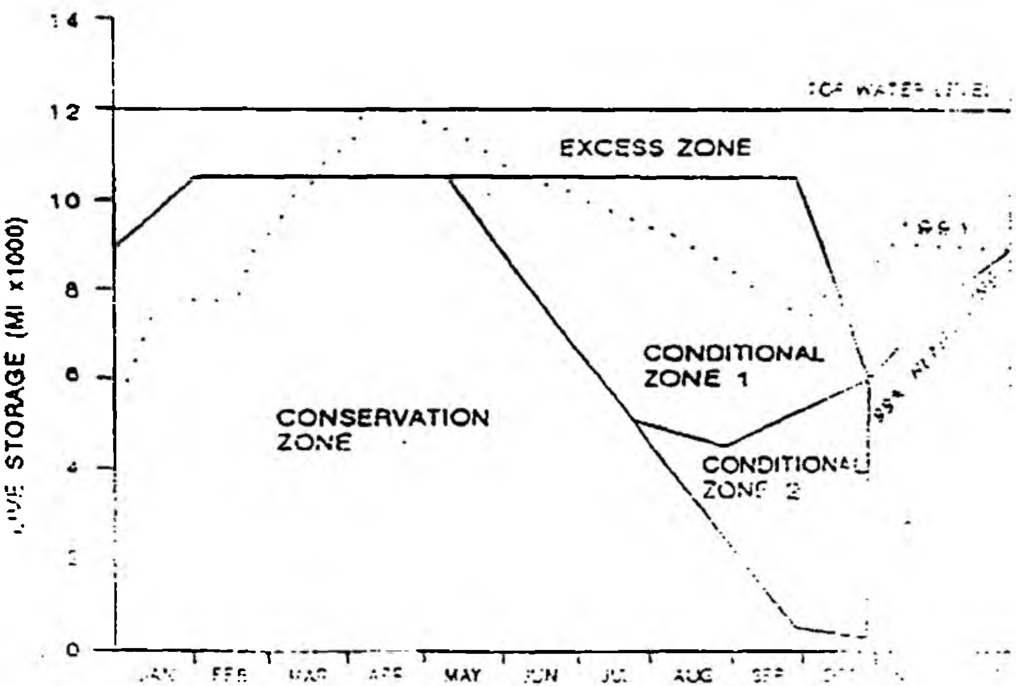
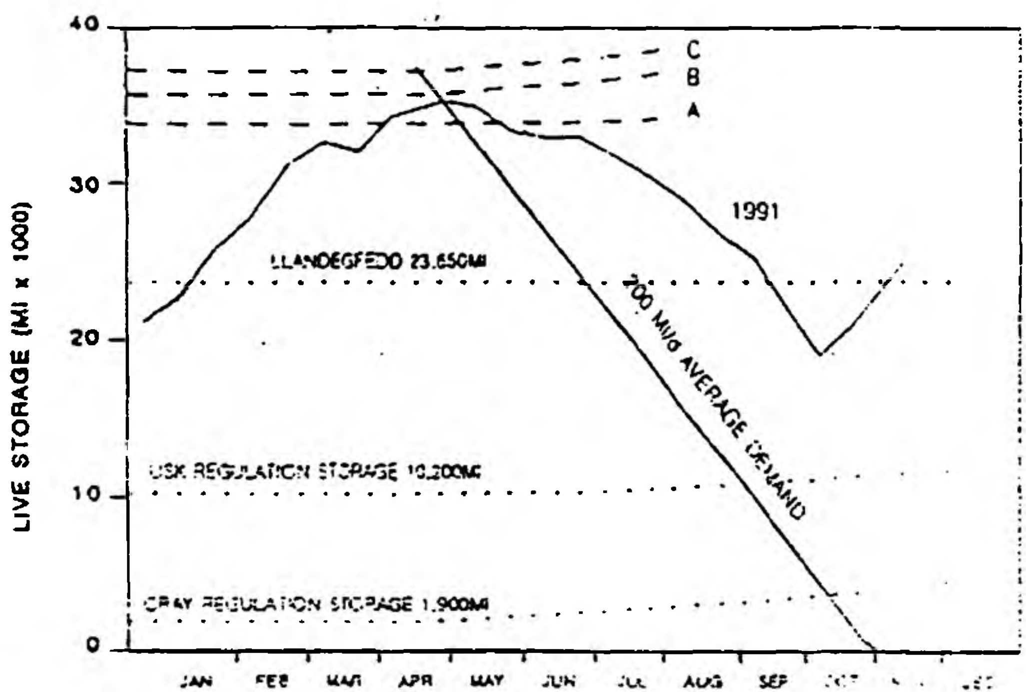


FIGURE 3: USK RESERVOIR CONTROL DIAGRAM


LIVE STORAGE (Ml x 1000)
40
30
20
10
0
C
B
A
1991
LLANDEGFEDO 23.650Ml
700 Ml/d AVERAGE DEMAND
USK REGULATION STORAGE 10,200Ml
CRAY REGULATION STORAGE 1,900Ml
JAN
FEB
MAR
APR
MAY
JUN
AUG
SEP

diagrams (Figures 2 and 3) and by varying the abstraction licence to remove the maintained flow condition initially on a trial basis.

21. Both Cray and Usk reservoirs are still able to provide a direct supply to the Swansea valley. This can be at rates of 43.2 Ml/d and 36 Ml/d respectively when storage allows. However the majority of the storage in these reservoirs is reserved initially for river regulation purposes to support supplies in the Conjunctive Resource area. As the year progresses the total quantities in storage are matched against demands on the Llandegfedd/Court Farm system to establish how much of the Cray and Usk storage needs to be retained for regulation purposes.

22. This is illustrated in Figure 2. This shows the available storage of Cray, Usk and Llandegfedd singly and aggregated on the vertical axis and the average demand line of 200 Ml/d plotted against the calendar on the horizontal axis. It should be noted that the demand curve terminates on the 1st November, the agreed drought end date. After that date, flows in the River Usk are assumed to have recovered sufficiently to allow unsupported direct abstraction.

23. Figure 2 demonstrates that the combined usable storage of the three reservoirs cannot guarantee to meet the average demand (assuming the onset of drought conditions) unless storage is at a maximum on the 5th May.

24. As the summer progresses, the storage required to meet the south east Wales demand reduces. Any surplus storage can be directed to the Swansea valley as direct supply. Thus if the total storage in Usk and Llandegfedd is in excess of 34,000 Ml on the 12th May it is possible to reallocate the remaining Cray storage for direct supply. If the Llandegfedd storage is in excess of 23,500 Ml after the 5th July the Usk Reservoir storage can be reallocated for direct supply.

25. Study of the River Usk drought flow records shows that the earliest date on which the 'put and take' condition could ever come into operation is the 10th May (1976). Using the flow recession characteristics of the River Usk, it is possible to forecast the minimum quantity that can be abstracted from the natural river flow up to [illegible] days in advance. Hence, with suitable flow conditions, the dates on which Cray and Usk can be reallocated to direct supply may be earlier than indicated in paragraph 25.

26. Figure 3 illustrates the control diagram for [illegible] Reservoir, which is used in conjunction with the [illegible] in Figure 2 and has been agreed by the [illegible]

27. This control diagram was constructed using the '10-Component Method' (Reference 2). Detailed explanation of the construction of the control rules is not given here. However the control rule diagram clearly defines how the reservoir should be operated. The EXCESS ZONE defines the storage position where refill is guaranteed and maximum direct supply can be taken. The CONSERVATION ZONE defines

where the priority must be to conserve storage for regulation against the onset of a drought and allows only the minimum direct supply abstraction. The CONDITIONAL ZONE defines the area where storage can be allocated between regulation and/or direct supply (Zone 1) or regulation with minimum direct supply only (Zone 2) as the summer progresses and the overall resource position unfolds.

FUTURE DEVELOPMENTS

28. An additional feature of Figure 3 which is currently being examined is the ability to make specific releases to the river purely for environmental and fishery considerations. If in the Autumn the storage is above the 99% refill curve and the full direct supply entitlement is being achieved, releases can be made for fishery purposes. This may benefit the full length of the river in Autumn and the operators can be secure in the knowledge that refill will not be compromised.

29. Other issues are the conditions for the River Usk abstractions, the relation of the River Usk regulation to control diagrams for the Taf Fawr and Taf Fechan sources, and the potential to vary current statutory compensation discharges.

CONCLUSION

30. The Consultative Group has brought together staff from both the NRA and Welsh Water to optimise existing resources and resolve matters of potential conflict. Progress to date is evidence of the positive results that can be achieved by close co-operation between the two organisations. These include improved supply security, operational flexibility and benefits to the river flows for migratory fish and the river in general

31. There remain many opportunities to operate this complex Conjunctive Resource Scheme in different ways to improve resource availability, improve river flows or improve resource security. The organisational framework is in place to enable these developments to be progressed.

ACKNOWLEDGEMENTS

The authors acknowledge the efforts of their colleagues on the Consultative Group. The views expressed here are the authors, and not those of their respective organisations.

REFERENCES

1. JACK W.L and LAMBERT A.O. 'Operational [illegible] Resources and Reservoir Engineering Conference. 199[illegible].
2. LAMBERT A.O. 'An Introduction to Operational Control Rules Using the 10-Component Method.' BHS Occasional Paper No 1, 1989.

b) Hands-off flow and Residual flow at Bryn Aled.

i) 1st June to 31st January inclusive:

when the residual flow at Bryn Aled Gauging Station is less than or equal to a hands-off flow of 29.5 Ml/d then the daily volume of regulation water released shall not be less than the Bryn Aled daily abstraction.

ii) 1st February to 31st May inclusive:

a minimum residual flow of 11.4 Ml/d is to be maintained downstream of Bryn Aled weir at all times.

3.2.3 Regulation/Augmentation Releases:

Releases are made to support the seasonally varying abstraction at Bryn Aled when the residual flow is less than or equal to the hands-off flow and during the period 1 February to 31 May inclusive to support the defined residual flow below the Bryn Aled intake.

3.2.4 Generation of Hydro-electricity:

No provision at present or foreseen.

3.2.5 Other Releases:

A total of up to 354 Ml, recalculated as of 1st April each year, is available to provide releases for fishery purposes. Additional releases of spare water may be released during autumn and winter conditional upon Aled Isaf seasonal storage. Details of the arrangements for discharging these releases are provided in the Operating Manual. (See 3.3 below).

It may from time to time be necessary to make releases from the reservoirs for reservoir safety or maintenance.

3.2.6 Flood Alleviation:

There are no explicit arrangements for the provision of storage for flood alleviation, but proposals for use of Aled Isaf reservoir for such purpose in the autumn and early winter may be brought forward.

3.3 <u>Operating Manual</u>

The detailed local arrangements for operation of the Aled Regulation Scheme will be specified in an Operating Manual.

The contents of the Operating Manual must be in accordance with the principles set out in this Agreement. The Operating Manual can be updated and revised as necessary without modification to this Operating Agreement, provided that such updates and revisions are agreed by both parties to this Agreement.

SCHEDULE 3 - MANAGEMENT RULES

3.1 General Principles

Llyn Aled and Aled Isaf provide storage for river regulation of the Afon Aled. The water from Bryn Aled is pumped to Plas Uchaf reservoir from where it gravitates to Glascoed Water Treatment Works. The treated water supplies a large part of the highly seasonal demand on the North Wales coast around Rhyl.

The direct supply yield of the Aled reservoirs has been calculated using 1984 hydrological data, assuming a statutory compensation water of 2.27 Ml/d from Aled Isaf. Based on these assumptions the safe yield to water supply is 13 Ml/d. The use of Llyn Aled and Aled Isaf for river regulation implies a safe yield in excess of 13 Ml/d. However in return for greater flexibility of operation and the implementation of the Operating Agreement the Undertaker has agreed to balance the potential loss of 'river regulation' yield against the benefit to the river interests of operating with the rare use of Drought Orders and flexibly using a basic allocation of storage for fishery freshet releases at crucial times of the fishery year.

The river regulation releases support abstractions by the Undertaker at Bryn Aled, compensation water releases from Aled Isaf, a residual flow for part of the year downstream of Bryn Aled intake and fishery releases in the autumn and winter.

These management rules, based on the assumption that the revised licence application will be successful, provide a framework for ensuring that the facilities are used to maximise operational yield while providing significant benefits for fisheries management and river interests in general.

3.2 River Regulation Commitments

3.2.1 Abstractions:

The river regulation releases from Llyn Aled and Aled Isaf are required to support a defined residual flow below the Bryn Aled intake on the Afon Aled and abstraction at Bryn Aled by the Undertaker.

3.2.2 Compensation Water and Hands-off Flows:

a) Statutory releases

Aled Isaf
Continuous 0.026 m^3/sec (2.27 Ml/d

A small Consultative Group (the Aled and Clwyd Consultative Group) shall exist to assist in the updating and revision of the Operating Manual. Its function will be to agree procedures for the release of regulation water and freshets for river management, procedures for emergencies and Drought Order applications, to agree any updating and revisions to the Operating Agreement, and to undertake such formal or informal discussions relevant to the Aled Regulation Scheme as may be necessary. The Consultative Group will consist of:-

2 representatives of the Undertaker, and

2 representatives of the Authority.

The names of the representatives are specified in the Operating Manual together with such other information as may be appropriate.

The Consultative Group may, in undertaking their duties, liaise with specific local riparian interests, and Statutory Conservation Bodies, as and when the Consultative Group members agree such liaison is appropriate.

The first issue of this operating manual is to be prepared by the Consultative Group representatives prior to 1 March 1990, after which the Undertaker will be responsible for its production and distribution.

3.4 Exchange of Information

Provision is to be made in the Operating Manual for data exchange between the Authority and the Undertaker in relation to reservoir levels and storages, river levels and flows and abstractions at any site where such data is measured so far as it relates to the operation of the "Aled Regulation Scheme".

3.5 Drought Management

It is recognised that the operational yield can only be safeguarded by conserving storage in the Spring of each year. The intended licence conditions ensure that Drought Orders will rarely be required and then only when the aggregated storage of Llyn Aled and Aled Isaf falls below the Aled System Drought Alert Curve as defined in the Aled Operating Manual. (See Figure 2).

3.6 Cost Apportionment

The Apportionment Ratio agreed is that the Authority shall contribute 100% of the costs as detailed in Schedule 4.

3.7 Other Relevant Matters

3.7.1 The Undertaker shall consult the Authority before varying the management of any land if that variation involves any matter which is the subject of this Agreement.

3.7.2 Any information which the Authority may acquire relating to pollution incidents which could adversely affect the operation of Bryn Aled intake or the quality of water abstracted is to be notified to the Undertaker without delay.

SCHEDULE 4 - FINANCIAL PROVISIONS

4.1 <u>Payments Dates</u>

Payments will be made by the Authority to the Undertaker in respect of each relevant financial year commencing 1 April as follows:-

4.1.1 Four quarterly Provisional Payments on 1 July, 1 October, 1 January and 31 March in that year.

4.1.2 Final Payment on whichever day shall be the later of 1 July following the end of the relevant year or thirty days after receipt by the Authority of the Statement of Final Total referred to in clause 4.4 below.

4.2 <u>Method of Payment</u>

Payments will be made by the Authority to the Undertaker by bank transfer, cheque or other reasonable means acceptable to the Undertaker.

4.3 <u>Amount of Payments</u>

4.3.1 Each Provisional Payment in respect of a relevant year will be of an amount equal to one quarter of the Forecast Net Operating Charge calculated in accordance with clause 4.6.

4.3.2 The Final Payment in respect of a relevant year will be of an amount equal to the difference between the Final Total in respect of that year as calculated in accordance with clause 4.4 and the sum of the Provisional Payments already made in respect of that year in accordance with clause 4.1.1.

4.4 <u>Final Total</u>

4.4.1 The Final Total in respect of a year commencing the 1 April shall be the sum of the percentage attributable to the Authority in accordance with the apportionment ratio in clause 3.6 of this Agreement of:

a) the expenses, excluding depreciation, wholly, exclusively and necessarily incurred in carrying out the duties in terms of Schedule 3 of this agreement, but excluding any costs associated with the operation of the Bryn Aled pumping station.

a) All proposals for works relating to construction and/or maintenance of land drainage facilities undertaken by the Authority, to be subject to consultation with the Undertaker prior to implementation and to be scheduled by joint agreement. In the case of items of work to be carried out by third parties under the Consent procedures of the Land Drainage Act 1976, the Authority will advise the applicant to consult with the Undertaker as to the scheduling of the works so as to avoid interruption to the Undertaker's abstraction at Dolbenmaen.

b) Any proposals for changes in land use, in the catchment area upstream of Dolbenmaen, which are the subject of planning consultation with the Authority, shall be made known to the Undertaker by the Authority, so that the Authority may convey to the local planning Authority any observations or objections to the proposals on the part of the Undertaker.

c) Any information which the Authority may acquire relating to pollution incidents which could adversely affect the operation of the Dolbenmaen intake or the quality of water abstracted is to be notified to the Undertaker without delay.

SCHEDULE 4 - FINANCIAL PROVISIONS

4.1 <u>Payments Dates</u>

Payments will be made by the Authority to the Undertaker in respect of each relevant financial year commencing 1 April as follows:-

4.1.1 Four quarterly Provisional Payments on 1 July, 1 October, 1 January and 31 March in that year.

4.1.2 Final Payment on whichever day shall be the later of 1 July following the end of the relevant year or thirty days after receipt by the Authority of the Statement of Final Total referred to in clause 4.4 below.

4.2 <u>Method of Payment</u>

Payments will be made by the Authority to the Undertaker by bank transfer, cheque or other reasonable means acceptable to the Undertaker.

4.3 <u>Amount of Payments</u>

4.3.1 Each Provisional Payment in respect of a relevant year will be of an amount equal to one quarter of the Forecast Net Operating Charge calculated in accordance with clause 4.6.

Elan

[illegible]

SUMMARY OF PERCEIVED AND MEASURED IMPACTS ON RIVERS DOWNSTREAM OF THE ELAN AND USK RESERVOIRS

ELAN RESERVOIRS

Geomorphology - No recorded impact. (Ron Clark - Monmouth)

Flooding - Only problem occurs if the reservoirs are emptied(Ron Clark- Monmouth)

Water Quality - Some unrecorded evidence that the impoundment has affected the temperature,DO and pH regime of the river d/s of the dam particularly at times of impoundment overspill. The water quality staff at Monmouth are about to start looking at the effects in more detail.
May have had an effect of increasing the amount of iron and manganese ions.(Paull 1978-unpublished MSc Thesis on Benthic Inverts and deposits in the R Elan) Mean concentrations of 0.5 Fe and 0.1Mn mg/l in the river Elan. This was 10 times the results in the upper Wye. Complicated by water treament works effluent and acidification problems also in the area. Upper Wye Catchment Management Plan 1993 - says the water quality may be effected by the impoundment.

Navigation/Recreation and Amenity - No recorded impacts. But knock-on effect of influencing angling success. General inconvenience of alterations in flow.

Aquatic Ecology - Ref The effects of Impoundment on the downstream Macroinvertebrate Riffle Fauna of the River Elan - R.J.Inverarity, G.D.Rosehill and M.P.Brooker 1983 pointed out that macroinverts pops in R.Elan d/s of reservoir were less diverse as compared to those in the river Wye. Could have been due to elevated iron and manganese (including deposition of iron and manganese salts on the substrate), reduced pH, reduced temperature or increased invertebrate drift due to high/fluctuating flows. All of which could have been caused by impoundment. Difficult to differentiate the effects of regulation from those of acidification in this catchment. Also see Caban Goch Reports.

Conservation/Terrestrial Ecology - No recorded impacts although it is necessarily a change in ecology from what was there before the reservoir was constructed. Changes in riverflow also affect riparian communities when there is an increase in the depth of the water.

Fisheries - Fish population immediately d/s of dam is very poor with only a few brown trout and pike present. Fish pop improves further downstream.
Temperature regime can be seen to affect the growth of juvenile salmon and trout but no formal report to show this. Could affect fry emergence and survival. Smolt migration is also affected by temperature and flow.
Large variations in flow cause unstable habitat for fish reproduction and may even lead to stranding of juveniles when wetted area of river bed is significantly reduced by impoundment. No direct evidence for this in the Elan.
Of course a large spawning area was lost in the creation of the reservoir.
Possible effect of various metals in the water restricts improvement in fisheries in the river Elan.

The altered flow regime must also necessarily have an effect on the fish population by inhibiting feeding activity and cause loss of food organisms due to invertebrate drift.

USK RESERVOIR

Geomorphology/Physical Impacts - No effect shown

Water Quality - **Only proper survey done was during drought to look at DO in Usk d/s of reservoir. Other problems envisaged include change in temperature and pH.**

Nav/Rec/Amenity - **No recorded effects.**

Aquatic Ecology - **No data to show a problem. As from this year we are monitoring the biology up and downstream of the reservoir so will be able to conclude something from this. Must have some effect on Biology due changes in flow regime, temperature etc. as in the Elan.**

Fisheries - ?.

Licence No. and Variation	Date Issued	Licence Holder	Relates to:
19/55/18/408	15 Jan 1985	Welsh Water Authority	Monmouth Pumping Station Licence to abstract water from the river at the rate of 30 million gallons per day. The abstraction to be supported by regulation discharge from Elan Valley when the flow at Redbrook is less than 266 million gallons per day in accordance with Licence No. 19/55/1/7.

SCHEDULE 3 - MANAGEMENT RULES

3.1 General Principles

The storage of the Elan Valley reservoirs is used to satisfy 3 specific requirements:-

a) To provide a direct supply to Severn Trent Water PLC Water Treatment Works at Frankley which is linked to the reservoirs by the Elan aqueduct at a distance of 118km.

b) To provide a direct supply to the Undertaker's Water Treatment Works at Elan Valley which provides the bulk of the public water supply for the communities of Rhayader, Llandrindod Wells and Builth Wells.

c) To provide river regulation/augmentation releases to the River Wye during periods of low flow and which facilitates the abstraction of water by Severn Trent Water PLC at Lydbrook and the Undertaker at Monmouth as part of the conjunctive use scheme to satisfy demands in South East Wales.

The General Principles covering the operation of the Regulation Scheme are dependent upon:-

i) Storage situation in the Elan Valley reservoirs.

ii) Rate of flow in the River Wye at Redbrook.

The following subsections identify the operating constraints defined in the abstraction and impounding licences granted under the Water Resources Act together with the general principles of the regulation scheme management so as to maximise the resource usage in satisfying the three demands specified above.

3.2 River Regulation Commitments

3.2.1 Abstractions

The river regulation releases from Caban Coch are required to support the licensed river abstraction by Severn Trent Water PLC at Lydbrook (Licence Number 19/55/18/375) and by the Undertaker at Monmouth (Licence Number 19/55/18/408). Both Licences contain specific conditions relating to the augmentation releases.

3.2.2 Compensation Water Discharge

The Elan reservoirs compensation water discharge is specified as a minimum of 68 Ml/d (15 mgd) and is measured at the gauging station 300 metres below Caban Coch dam known as Elan Village weir.

There are no compensation requirements for Claerwen, Dol-y-Mynach, Craig Goch or Pen-y-Garreg reservoirs.

3.2.3 Regulation/Augmentation Releases

Regulation/augmentation releases are made in addition to the compensation water releases described above and are used to support a flow of 1210 Ml/d (266 mgd) in the River Wye as measured at Redbrook gauging station. The regulation/augmentation releases are subject to:-

i) A maximum augmentation release of 164 Ml/d (36 mgd) when storage in the Elan Valley reservoirs is above the rule curve (Figure 2).

ii) A maximum of 136 Ml/d (30 mgd) when storage is below the rule curve.

The maximum total release that can be made during periods of augmentation is either 232 Ml/d (68 Ml/d compensation + 164 Ml/d augmentation) or 204 Ml/d dependent upon the storage situation.

Augmentation releases commence when the gauged flow at Redbrook gauging station falls below 1210 Ml/d.

3.2.4 Generation of Hydro electricity

The two turbines at Caban are each capable of passing 68 Ml/d (15 mgd). As far as possible all releases of water into the River Elan are passed through the turbines but subject to the constraints imposed by the available head and flow rate.

Sufficient water to run both turbines (i.e. 118 Ml/d) can be released from Caban provided that the total reservoir storage is greater than the Upper Rule curve shown in Figure 2.

The two turbines at Claerwen are used only for lighting purposes inside the dam.

The Undertaker may in the future make proposals for increased use of one or more of the Elan Valley reservoirs for increased hydro electricity generation and these will be considered by the Consultative Group.

3.2.5 Other Releases

A total of 1818 Ml (400 million gallons) is available for freshet releases from the time that the Reservoirs are full until the next occasion when they are full but subject to a maximum of 1818 Ml in any calendar year. Freshets will only be released when requested by the Authority.

It may from time to time be necessary to make releases for reservoir safety and maintenance.

3.2.6 Flood Alleviation

The drawdown of the reservoirs resulting from normal operational practice provide incidental benefits for flood alleviation on the Rivers Elan and Wye.

Although there has been no explicit use of the reservoirs for flood alleviation to date the Authority may make proposals for flood alleviation releases in the future and these will be considered by the Consultative Group (See 3.3 below).

3.3 Operating Manual

The detailed local arrangements for operation of the River Wye Regulation Scheme will be specified in an Operating Manual.

The contents of the Operating Manual must be in accordance with the principles set out in this Agreement. The Operating Manual can be updated and revised as necessary without modification to the Operating Agreement, provided that such updates and revisions are agreed by both parties to this Agreement.

A small Consultative Group (the River Wye Consultative Group) shall exist to assist in the updating and revision of the Operating Manual. Its function will be to agree procedures for the release of regulation water and freshets for river management, procedures for emergencies and Drought Order applications, to agree any updating and revisions to the Operating Agreement, and to undertake such formal or informal discussions relevant to the River Wye Regulation Scheme as may be necessary. The Consultative Group will consist of:-

2 representatives of the Undertaker, and

2 representatives of the Authority.

The names of the representatives are specified in the Operating Manual together with such other information as may be appropriate.

The Consultative Group may, in undertaking their duties, liaise with specific local riparian interests, Land and Leisure Tir a Hamdden Ltd. and Statutory Conservation Bodies, as and when the Consultative Group members agree such liaison is appropriate.

The first issue of this operating manual is to be prepared by the Consultative Group representatives prior to 1 March 1990, after which the Undertaker will be responsible for its production and distribution.

3.4 Exchange of Information

Provision is to be made in the Operating Manual for data exchange between the Authority and the Undertaker in relation to reservoir levels and storages, river levels and flows and abstractions at any site where such data is measured so far as it relates to the operation of the "River Wye Regulation Scheme".

3.5 Drought Management

The Operating Manual shall contain details of the operational management of the River Wye Regulation Scheme under drought conditions. This will include the Lower Rule Curve shown in Figure 2 which is an agreed action line. When storage in the Elan Valley Reservoirs falls below this line then the following actions are taken:-

a) Abstractions from the Caban Coch reservoir have a revised maximum value of 327 Ml/d.

b) Abstractions from the river Wye at Monmouth and Lydbrook have reduced maximum values of 114 Ml/d and 40 Ml/d respectively.

c) Augmentation releases from Caban Coch have a revised maximum value of 136 Ml/d.

d) Discussions commence between the Undertaker and the Authority on the timing and nature of Drought Orders.

3.6 Cost Apportionment

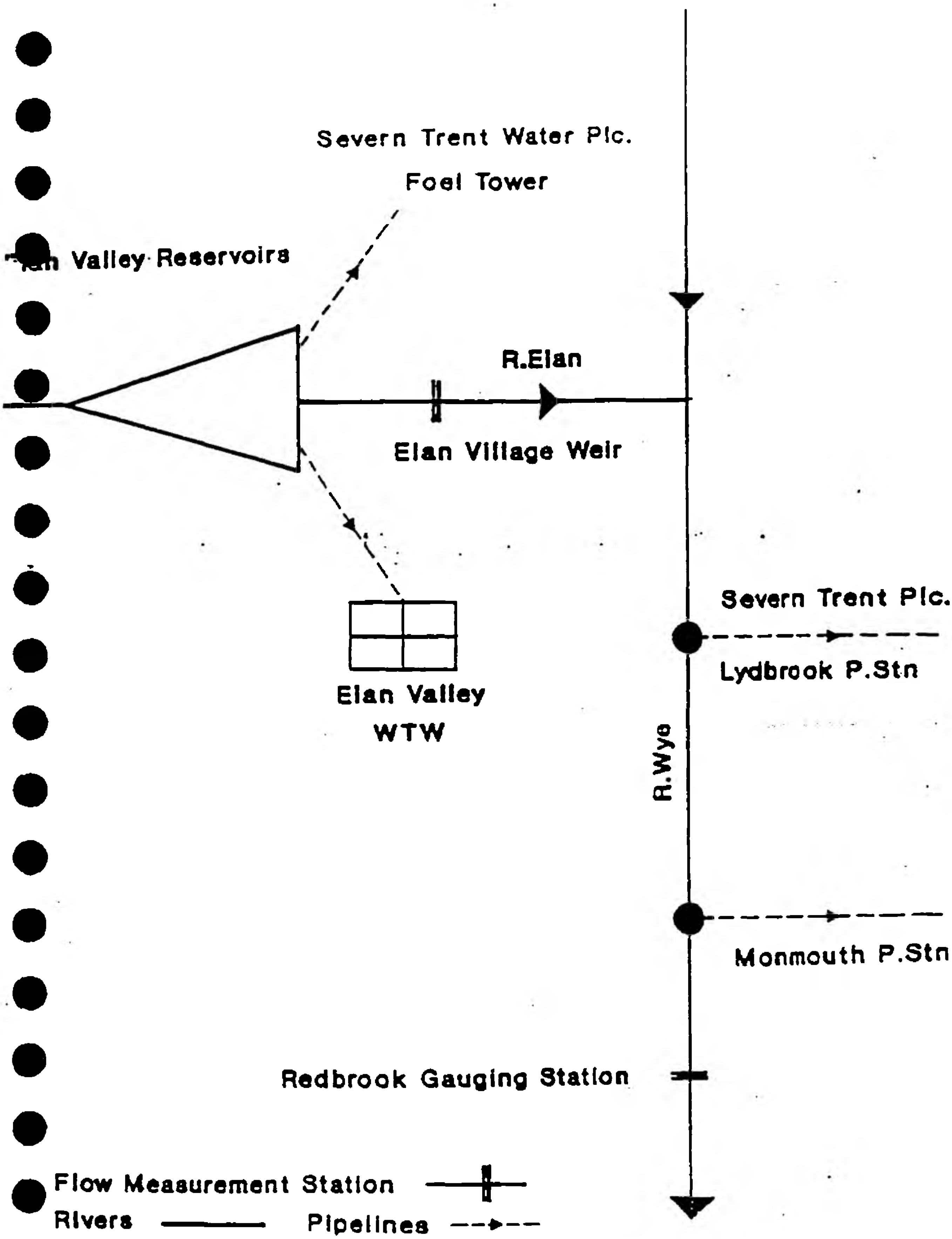
Simulations were carried out using hydrological data for 1976 and 1984 together with the present day water resources and supply system as described in this Agreement. Cost apportionment is based upon the average of the relative use of the Elan reservoirs storage during the two droughts as follows:-

Direct Supply :	18 February 1976 to 24 September 1976	75182 Ml
	27 February 1984 to 8 September 1984	66382 Ml
		141564 Ml
River Regulation :	18 February 1976 to 24 September 1876	19725 Ml
	27 February 1984 to 8 September 1984	13165 Ml
		32890 Ml

Total use of Elan reservoirs - 174454 Ml

Portion to be borne by the Authority - 32890 / 174454 - 19%

Sketch of System



RIVER WYE REGULATION SCHEME

Figure 1

Usk

9

APPENDIX 2C TO SCHEDULE 2

Commitment to a third party relating to Clwyd Regulation

Mr J R Davies, Gwynant, 44 Church Street, Flint

In consideration of his withdrawal of his objection when the Scheme was first advertised, Welsh Water agreed in an exchange of letters to undertake three gauging surveys, at and downstream of Pont-y-Cambwll, each summer at low flows, to check that the residual flows in the vicinity of Pont Dafydd are not less than natural residual flows. This commitment will pass to the Authority.

SCHEDULE 3 - MANAGEMENT RULES

3.1 General Principles

Boreholes in the Triassic Sandstone of the Vale of Clwyd are used as the principle source of water for river augmentation of the Afon Clwyd. In addition a statutory provision allows augmentation discharges of water from the Alwen Aqueduct which provides a significant import of potable water supply into the Vale of Clwyd and crosses the Vale south of Ruthin. Water is pumped to supply from boreholes at Llannerch adjacent to the river, which act effectively as a naturally filtered river abstraction. This source is used conjunctively with the Aled Regulation Scheme. (See Figure 1).

The Scheme operates on the 'Hands-off flow' principle using the Gauging Station at Pont-y-Cambwll. The Scheme was promoted on the basis that the natural low flows downstream of Llannerch would not be adversely affected and this has been confirmed by gauging surveys. The augmentation discharges are particularly beneficial in enhancing the very low natural summer flows in the Afon Clwyd between Ruthin and the confluence with the river Wheeler.

Formal operation of the Scheme only requires that the augmentation releases match the three-day average abstraction at Llannerch. However, if the artesian augmentation boreholes are allowed to discharge continuously between early May and Autumn (thereby frequently providing more augmentation release than is required to support abstraction) there will be additional benefits to the river environment for the whole of the river downstream of Ruthin. In addition, the Undertaker agrees to provide up to 1 Ml/d of augmentation releases on request from the Authority, subject to the current applications for Orders and abstraction licences (see Appendices 2A and 2B) being authorised without amendment. This facility for additional augmentation releases is to provide the Authority with flexibility in dealing with other future abstraction licence applications in the Vale of Clwyd.

These management rules provide a framework for ensuring that the facilities are used not only to meet supply requirements but also to provide such benefits for river interests in general as are feasible. It should be noted that several of the boreholes are dual purpose, and are switched from augmentation to direct supply when the Alwen Aqueduct supply is not available, during emergencies or maintenance periods.

3.2 River Regulation Commitments

3.2.1 **Abstractions:**

The river augmentation releases are required to support abstraction of up to 13.6 Ml/d at Llannerch by the Undertaker, and such other abstractions up to 1 Ml/d in total at other unspecified locations as may be approved by the Authority.

3.2.2 Compensation Water and Hands-off Flows:

a) Compensation water:

There are no compensation water provisions.

b) Hands-off flow:

When the residual flow at Pont y Cwmbwll Gauging Station is less than or equal to the Hands-off flow of 1.7 m3/s (147 Ml/d) then the daily volume of augmentation water released shall not be less than the Llannerch three-day average volume of abstraction (full details in Licence No. 24/66/3/48).

3.2.3 Regulation/Augmentation Releases:

Such releases as are necessary to support the seasonally varying abstractions when the Pont y Cambwll flow is less than or equal to the Hands-off flow.

3.2.4 Generation of Hydroelectricity:

None

3.2.5 Other Releases:

Releases from artesian augmentation boreholes between early May and autumn frequently exceed downstream abstraction requirements thereby conferring additional benefits to the river environment. There is no specific provision for fishery freshets.

3.2.6 Flood alleviation:

No provision feasible.

3.3 <u>Operating Manual</u>

The detailed local arrangements for operation of the River Clwyd Regulation Scheme will be specified in an Operating Manual.

The contents of the Operating Manual must be in accordance with the principles set out in this Agreement. The Operating Manual can be updated and revised as necessary without modification to the Operating Agreement, provided that such updates and revisions are agreed by both parties to this Agreement.

A small Consultative Group (the River Aled and Clwyd Consultative Group) shall exist to assist in the updating and revision of the Operating Manual. Its function will be to agree procedures for the release of regulation water and freshets for river management, procedures for emergencies and Drought Order applications, to agree any updating and revisions to the Operating Agreement, and to undertake such formal or informal discussions relevant to the River Clwyd Regulation Scheme as may be necessary. The Consultative Group will consist of:-

2 representatives of the Undertaker and

2 representatives of the Authority.

The names of the representatives are specified in the Operating Manual together with such other information as may be appropriate.

The Consultative Group may, in undertaking their duties, liaise with specific local riparian interests, and Statutory Conservation Bodies, as and when the Consultative Group members agree such liaison is appropriate.

The first issue of this operating manual is to be prepared by the Consultative Group representatives prior to 1 March 1990, after which the Undertaker will be responsible for its production and distribution.

3.4 <u>Exchange of Information</u>

Provision is to be made in the Operating Manual for data exchange between the Authority and the Undertaker in relation to groundwater levels and discharges, river levels and flows and abstractions at any site where such data is measured so far as it relates to the operation of the River Clwyd Regulation Scheme.

3.5 <u>Drought Management</u>

This Scheme has been successfully tested in the droughts of [illegible] and 1984 and it is considered that only exceptionally dry sequences of winters and summers could affect the operational yield. There is no Drought Alert Curve appropriate to this situation but close liaison via the Aled and Clwyd Consultative Group should enable potentially difficult drought situations to be identified in advance and appropriately managed with full regard for all river interests.

3.6 ~~3.5~~ Cost Apportionment

The Apportionment Ratio agreed is that the [illegible] shall contribute 100% of the costs as detailed in Schedule .

3.7 Other Relevant Matters

3.7.1 The Undertaker shall consult the Authority before varying the management of any land if that variation involves any matter which is the subject of this Agreement.

3.7.2 Any information which the Authority may acquire relating to pollution incidents which could affect the operation of the Llannerch boreholes or the quality of water abstracted is to be notified to the Undertaker without delay.

SCHEDULE 4 - FINANCIAL PROVISIONS

4.1 **Payments Dates**

Payments will be made by the Authority to the Undertaker in respect of each relevant financial year commencing 1 April as follows:-

4.1.1 Four quarterly Provisional Payments on 1 July, 1 October, 1 January and 31 March in that year.

4.1.2 Final Payment on whichever day shall be the later of 1 July following the end of the relevant year or thirty days after receipt by the Authority of the Statement of Final Total referred to in clause 4.4 below.

4.2 Method of Payment

Payments will be made by the Authority to the Undertaker by bank transfer, cheque or other reasonable means acceptable to the Undertaker.

4.3 Amount of Payments

4.3.1 Each Provisional Payment in respect of a relevant year will be of an amount equal to one quarter of the Forecast Net Operating Charge calculated in accordance with clause 4.6.

4.3.2 The Final Payment in respect of a relevant year will be of an amount equal to the difference between the Final Total in respect of that year as calculated in accordance with clause 4.4 and the sum of the Provisional Payments already made in respect of that year in accordance with clause 4.1.1.

C. Brynkir Woollen Mill (2 Agreements)

25.4.84: Agreement [illegible] charges which would otherwise be payable under the Scheme of Abstraction Charges. Subject to 1 yrs notice by either Brynkir Woollen Mill or the Authority.

1.1.89: **20 year Agreement to increase, reduce or suspend discharges from Cwmystradllyn for Brynkir Mill. The Undertaker responsible for implementation and payment of compensation to the Mill when such discharges are released or suspended.**

D. Fishing in Cwmystradllyn

Under an agreement dated 1.1.85, Pwllhelli and District Angling Association have the fishing rights at Cwmystradllyn Reservoir until 1992. As they were marginally concerned that Welsh Water's proposals for emergency pumping from below the lowest gravity intake might affect their fish stocks, in an exchange of letters (prior to the advertisement of the revised licences in 1987) it was agreed that any losses of fish arising from temporary pumping would be replaced by Welsh Water Authority, and this responsibility passes to the Undertaker.

SCHEDULE 3 - MANAGEMENT RULES

3.1 General Principles

Llyn Cwmystradllyn is the principal mains water supply source for the Lleyn Peninsula and the reservoir storage is used conjunctively on a seasonal basis for both direct supply and river regulation. The river regulation supports abstractions by the Undertaker at Dolbenmaen (when required), diurnally varying abstractions by Brynkir Mill, compensation water and freshet releases for a river system which is an important migratory fishery.

Experience in the 1984 drought clearly demonstrated that, as current demands are close to operational yield, Drought Orders would be required each dry spring and summer if the system is managed so as to minimise operating costs. However if the system is managed so as to maximise the operational yield (at extra cost to the Undertaker in some years) as is the intention under this Agreement, then Drought Orders should only be required to assist refill in severe dry winters.

These management rules provide a framework for ensuring that the facilities are used to maximise operational yield while providing significant benefits for fisheries management and river interests in general.

3.2 River Regulation Commitments

3.2.1 Abstractions:

The river regulation releases from Llyn Cwmystradllyn are required to support licensed abstractions by Brynkir Mill and by the Undertaker at Dolbenmaen.

3.2.2 Compensation Water and Hands-off Flows:

Cwmystradllyn: Continuous uniform compensation water 3.01 Ml/d.

Dolbenmaen: When the residual flow at Dolbenmaen Gauging Station is less than or equal to the Hands-off flow of

29.5 Ml/d (6.5 mgd) between 1 September and 22 May

or 59.1 Ml/d (13 mgd) between 23 May and 31 August

then the daily volume of regulation water released (in addition to the Cwmystradllyn compensation water) shall not be less than the Dolbenmaen daily abstraction (full details in Licence No. 23/65/8/16 Var. No. 1).

3.2.3 Regulation/Augmentation Releases:

Releases for Brynkir Mill: intermittent discharges totalling [illegible]7.45 Ml per week which may be varied (or suspended as a water conservation or river management measure) upon payment of weekly financial compensation by the Undertaker to Brynkir Mill.

Releases for the Undertaker at Dolbenmaen: such variable releases as are necessary to support the required seasonally varying abstraction whenever the Dolbenmaen residual flow is less than or equal to the Hands-off flow. The daily discharges for Brynkir Mill can be counted as part of the release for the Dolbenmaen abstraction.

Process/washwater return from Cwmystradllyn treatment works can be counted as regulation release subject to discharge consent.

3.2.4 Generation of Hydroelectricity:

Brynkir Mill abstraction is principally used for generation of power using a small turbine to run the Mill.

3.2.5 Other releases:

To provide for fishery management and angling purposes-random freshet releases of not less than 159 Ml (35 mg) between the 1 April and [illegible] November each year, plus additional random freshet releases conditional on Cwmystradllyn seasonal storage.

In dry weather flow conditions, the regulation discharges for Brynkir Mill may be suspended to limit the range of 24 hour variations of flows downstream of Dolbenmaen to avoid adverse effects on the river environment.

It may from time to time be necessary to make releases from Cwmystradllyn for reservoir safety or maintenance.

3.2.6 Flood Alleviation:

The refill characteristics of Cwmystradllyn do not permit any explicit arrangements for flood alleviation purposes.

3.3 <u>Operating Manual</u>

The detailed local arrangements for operation of the Dwyfor Regulation Scheme will be specified in an Operating Manual.

The contents of the Operating Manual must be in accordance with the principles set out in this Agreement. The Operating Manual can be updated and revised as necessary without modification to the Operating Agreement, provided that such updates and revisions are agreed by both parties to this Agreement.

A small Consultative Group (the Dwyfor Consultative Group) shall exist to assist in the updating and revision of the Operating Manual. Its function will be to agree procedures for the release of regulation water and freshets for river management, procedures for emergencies and Drought Order applications, to agree any updating and revisions to the Operating Agreement, and to undertake such formal or informal discussions relevant to the Dwyfor Regulation Scheme as may be necessary. The Consultative Group will consist of:-

2 representatives of the Undertaker and

2 representatives of the Authority.

The names of the representatives are specified in the Operating Manual together with such other information as may be appropriate.

The Consultative Group may, in undertaking their duties, liaise with specific local riparian interests, and Statutory Conservation Bodies. as and when the Consultative Group members agree such liaison is appropriate.

The first issue of this operating manual is to be prepared by the Consultative Group representatives prior to 1 March 1990, after which the Undertaker will be responsible for its production and distribution.

3.4 Exchange of Information

Provision is to be made in the Operating Manual for data exchange between the Authority and the Undertaker in relation to reservoir levels and storages, river levels and flows and abstractions at any site where such data is measured so far as it relates to the operation of the "Afon Dwyfor Regulation Scheme".

3.5 Drought Management

It is recognised that the operational yield can only be safeguarded, without recourse to frequent summer Drought Orders, by the Undertaker taking early action, when needed, to safeguard winter refill and avoid premature spring drawdown of Cwmystradllyn. This will occasionally incur extra operating costs, on an 'insurance' basis, particularly in respect of conditional winter operation of Dolbenmaen which is normally shut-down between late October and mid-March. The suspension of the Brynkir Mill regulation discharges is also an essential water conservation measure.

In exceptionally dry winters such as 1933/34 the inflow to Cwmystradllyn is insufficient even to meet the 3 Ml/d compensation water requirement. Large drawdowns in autumn will therefore necessitate a winter Drought Order to reduce the compensation water discharge. However, natural Afon Dwyfor flows at Dolbenmaen are sufficient, throughout the driest winters, to permit virtually continuous unsupported abstraction.

The main principles of drought management are summarised in the seasonal control rule for Cwmystradllyn reservoir (Figure 2); it may be modified by agreement of the Dwyfor Consultative Group.

3.6 Cost Apportionment

A simulation was carried out using hydrological data for 1984 together with the present day operating procedures and seasonal demands. The resulting cost apportionment is as follows:-

Direct Supply : 3 February 1984 to 3 September 1984 1831 Ml

River Regulation : 3 February 1984 to 3 September 1984 566 Ml

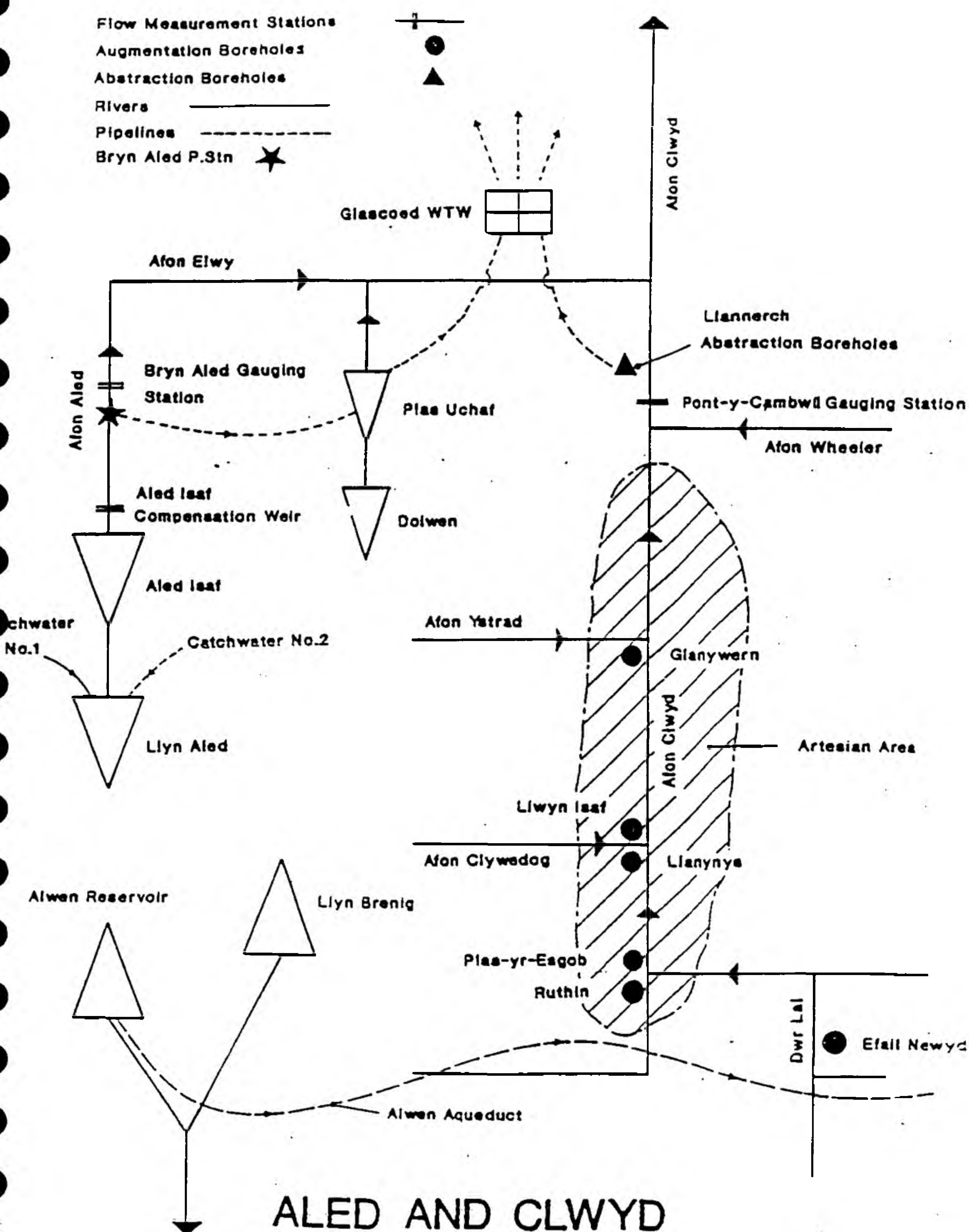
Portion to be borne by the Authority = $\frac{566}{1831+566}$ = 24%

3.7 Other Matters

3.7.1 The Undertaker shall consult the Authority before varying the management of any land if that variation involves any matter which is the subject of this Agreement.

3.7.2 In recognition of the potential operational problems which catchment activities upstream of the Dolbenmaen intake can cause the Undertaker, particularly in the period April to October inclusive, the Authority agree to the following arrangements:

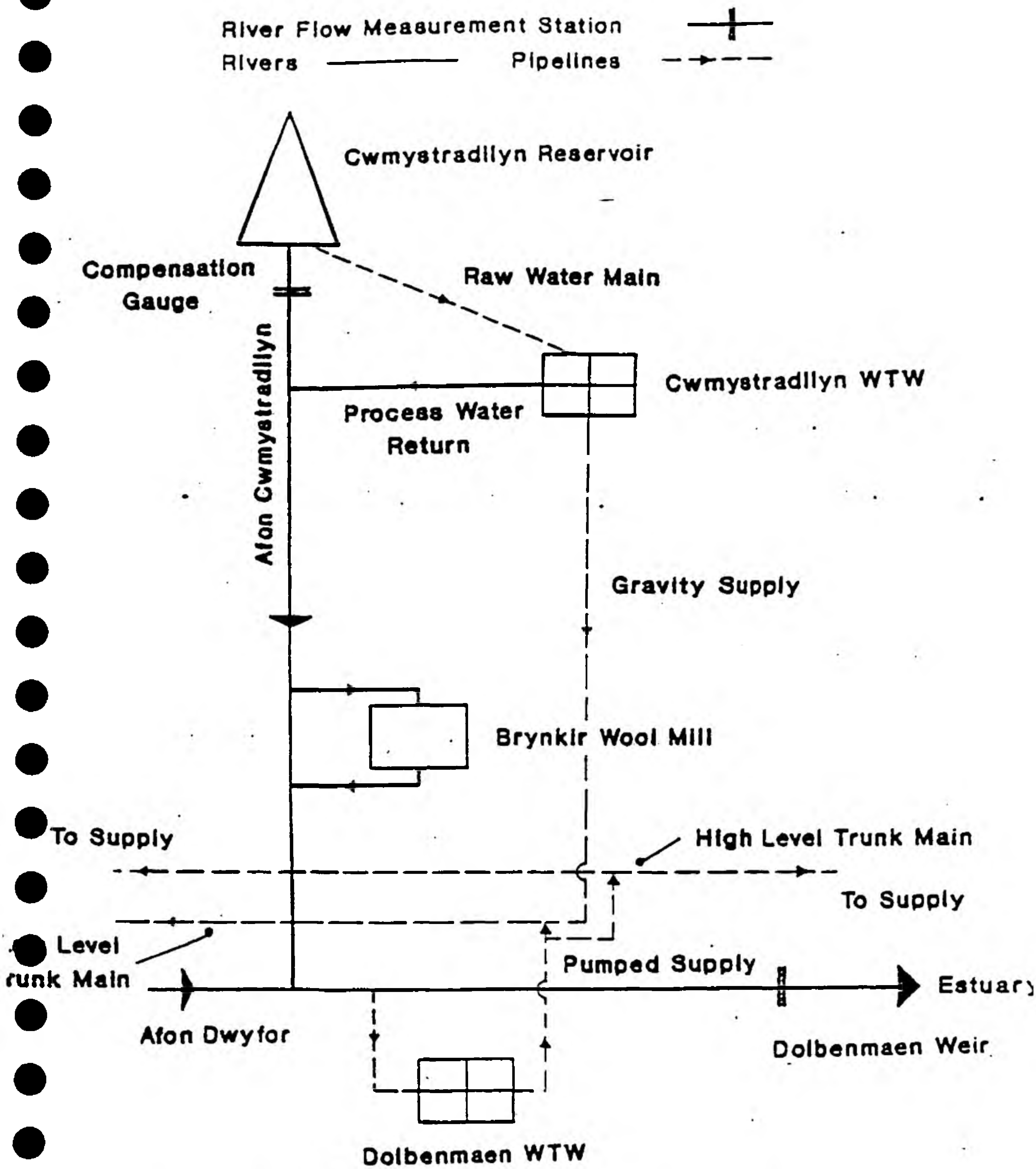
Sketch of System



ALED AND CLWYD REGULATION SCHEMES

Figure

Sketch of System



DWYFOR REGULATION SCHEME

Figure 1

0-13

Dee

SCHEDULE 3 - MANAGEMENT RULES

3.1 General Principles

The Dee Regulation Scheme is unusual in that the detailed application of matters formalised in Statutory Instruments and licences is subject to the over-riding framework of the Dee and Clwyd River Authority Act 1973 (subject to minor modifications in parallel with the 1989 Water Act). Both detailed and general principles are set out in the Dee General Directions which are modified from time to time through the Statutory Dee Consultative Committee.

Section 9 of the Dee and Clwyd River Authority Act 1973 specifies the present statutory framework for regulation of the river Dee by the Authority using Llyn Tegid, Llyn Celyn and Llyn Brenig. Appropriate amendments to the Dee and Clwyd River Authority Act 1973 will be required, to incorporate necessary redefinition and clarification consequent upon the formation of the Authority, and the occasional use of Alwen reservoir for minor river regulation releases: General Directions will be issued by the Authority consisting of Normal General Directions and Drought General Directions.

The general principles for river regulation under the provisions and safeguards of the Dee and Clwyd River Authority Act 1973 relate to the definition of a maintained flow of specified magnitude and location (except during a drought more severe than the design drought of estimated return period of once in 100 years) whilst having regard to:

i) Mitigating flooding.

ii) Supplying British Waterways Board, Shropshire Union Canal with 0.328 cubic metres per second.

iii) Safeguarding the fisheries.

iv) Any other purposes which, in the opinion of the Authority, are appropriate and consistent with the purposes aforesaid.

Drought General Directions, subject to reasonable approval of the Consultative Committee, are to prescribe the principles and detail, as required, to reduce prescribed flows or abstractions in a drought more severe than the design drought.

The Authority is empowered to issue Emergency Drought General Directions to cover unforeseen situations arising at short notice and a disputes procedure is also allowed for.

The abstraction licences of 'Designated Abstractors' include a provision whereby they agree to abide by the provisions of the Dee Drought General Directions and temporarily reduce their abstracted quantities. Designated Abstractors, each having one representative on the Dee Consultative Committee, are as follows:

The Undertaker

North West Water plc

Wrexham and East Denbighshire Water Company

Chester Waterworks Company

In addition the British Waterways Board have one representative on the Dee Consultative Committee and a statutory abstraction right (in respect of navigation on the Shropshire Union Canal) which is not subject to reduction under Drought General Directions. The Authority has three representatives on the Dee Consultative Committee, and the amendments to the 1973 Act propose that the operators of Llyn Celyn, Llyn Brenig and Alwen reservoir also have one representative (between them) on the Dee Consultative Committee.

This Operating Agreement deals only with the management rules necessary for the effective day-to-day operation between the Undertaker and the Authority of Llyn Celyn, Llyn Brenig and Alwen reservoir within the Dee Regulation System.

3.2 River Regulation Commitments

3.2.1 Abstractions:

The Undertaker is one of several licensed abstractors on the regulated river Dee. This Operating Agreement does not confer any additional benefits to the Undertaker as an abstractor, over and above those which they already enjoy as a Designated Abstractor on the Dee Consultative Committee.

As the Operator of the Bala Sluices the Authority has responsibility for ensuring that adequate flows are maintained in the river Dee for abstraction and other river regulation purposes.

The Undertaker has the responsibility of ensuring that releases as specified by the Authority are made from Llyn Celyn and Llyn Brenig to enable the Authority to meet its responsibilities.

3.2.2 Compensation Water Releases:

Statutory releases from the Undertaker's reservoirs

Llyn Celyn:

1st October - 31st March: 0.368 cubic metres per second (31.8 Ml/d)
1st April - 30th September: 0.737 cubic metres per second ([illegible] Ml/d)

Brenig/Alwen - Minimum combined:

1st October - 31st March: 0.158 cubic metres per second (13.6 Ml/d)
1st April - 30th September: 0.289 cubic metres per second (25.0 Ml/d)

subject to a minimum release of 0.053 cubic metres per second (4.5 Ml/d) from either reservoir.

3.2.3 **Regulation/Augmentation Releases:**

Under Normal General Directions the releases from the four regulating reservoirs are used to support a variable maintained flow on the river Dee which is sufficient to provide a design residual flow over Chester Weir after the abstractions have been made. The maintained flow and measurement points are defined in the Dee General Directions.

Under Drought General Directions the releases from the regulating reservoirs must be sufficient to provide net abstraction requirements and an approximation to the natural flow over Chester Weir, except during the 'spring tide' periods when additional releases are necessary.

The hydro-electric power station at Llyn Celyn is also used within the overall constraints of the Dee Regulation System to maximise income from Merseyside and North Wales Electricity Board. This is recognised by the Authority as a 'purpose' so long as it is undertaken in a manner which is appropriate and consistent with maintaining flows, mitigating flooding, supplying British Waterways Board and safeguarding fisheries.

3.2.4 Generation of Hydro Electricity:

All releases from Llyn Celyn and Alwen reservoir can pass through turbines to generate electricity from the otherwise unused water energy.

To allow limited peak power generation at Llyn Celyn for income maximisation at any time, 22 cumec-days of the Special Release Allocation (see 3.2.5 below) is specifically allocated for the use of the Undertaker.

A hydro-electricity facility may also be developed at Llyn Brenig in future.

3.2.5 Other Releases:

Special releases for water quality purposes - to mitigate the effects of adverse water quality below the reservoirs in accordance with pollution emergencies procedures (Deepol).

Special releases for canoeing events on the Afon Tryweryn on a number of pre-specified days a year, together with re-arrangement of weekly releases to maximise the use of the Canolfan Tryweryn facilities at weekends whenever feasible between May and October inclusive. The charges paid by Canolfan Tryweryn for rescheduled releases will accrue to the Undertaker.

It may from time to time be necessary to make releases from the reservoirs for reservoir safety or maintenance. In particular, the Undertakers must ensure that Llyn Celyn discharges at the maximum rate wherever it exceeds maximum retention level, irrespective of conditions downstream. The maximum retention level of Llyn Celyn is related to the maximum capacity of the existing spillway, and may not be altered by the Authority without the approval of the Undertaker and the Inspecting Engineer.

Fishery freshets - substantial special releases are made, mainly during

i) the grilse run (July).

ii) spawning runs up the Alwen and Tryweryn tributaries (October - December) and the operation of the fish traps.

iii) 'spring tide' periods under Drought General Directions.

These releases are made to safeguard fisheries, not to optimise fishing conditions.

A reserved amount of storage of 119 cumec-days (1028 Ml) recalculated from 1 April each year, known as the Special Release Allocation is split into two parts; 100 cumec-days in Llyn Celyn and the remaining 19 cumec-days in Llyn Brenig. 22 cumec-days of the Llyn Celyn allocation is allocated to the Undertaker for peak hydropower generation.

"Other releases" may include releases by the Authority for the above purposes, and any other purposes which are appropriate and consistent with the principle purposes of regulation. The Special Release Allocation, together with opportunistic use of spare storage may be used by the Authority for all or some of the above "Other Releases".

3.2.6 Flood Alleviation:

Llyn Brenig will not be explicitly operated for day-to-day flood mitigation, other than to have a normal maximum retention level 0.15 m below spillway.

Llyn Celyn and Llyn Tegid will be used for short-term retention of flood run-off for flood mitigation purposes on the river Dee, as specified in the Dee General Directions.

Alwen reservoir will not be explicitly operated for day-to-day flood mitigation.

3.3 Operating Manual

The overall arrangements for the operation of the Dee Regulation Scheme are specified in the Dee General Directions which will be updated and revised by the Authority from time to time. The Dee Consultative Committee has the function to assist the Authority in the formulation of General Directions and the duty of commenting to the Authority upon any such Directions as proposed or issued by the Authority. The Authority shall, in preparing any such Directions, consult the Committee and shall have regard to any views expressed to them by the Committee with respect to such Directions. Drought General Directions shall be subject to the reasonable approval of each of the bodies represented on the Committee.

A small Consultative Group (the Dee Consultative Group) shall exist to assist in the updating and revision of an Operating Manual, which will detail the working arrangements between the Authority and the Undertaker within the overall context of the General Directions and this Operating Agreement. Its function will be to agree procedures for the release of regulation water and freshets for river management, procedures for emergencies, to agree any updating and revisions to the Operating Agreement, and to undertake such formal or informal discussions relevant to the Dee Regulation Scheme as may be necessary. The Consultative Group will consist of:-

2 representatives of the Undertaker and

2 representatives of the Authority.

The names of the representatives will be specified in the Operating Manual together with such other information as may be appropriate.

The Consultative Group may, in undertaking their duties, liaise with specific local riparian interests, Land and Leisure Tir a Hamdden Ltd. and Statutory Conservation Bodies, as and when the Consultative Group members agree such liaison is appropriate.

The first issue of this operating manual is to be prepared by the Consultative Group representatives prior to 1 March 1990, after which the Undertaker will be responsible for its production and distribution.

3.4 Exchange of Information

Provision is to be made in the Operating Manual for data exchange between the Authority and the Undertaker in relation to reservoir levels and storages, river levels and flows and abstractions at any site where such data is measured so far as it relates to the operation of the "Dee Regulation Scheme".

3.5 Drought Management

Pre-planned conservation measures can be implemented under the Dee Drought General Directions, which may be introduced when total storage of Llyn Celyn and Llyn Erenig falls below the seasonal 'System Conservation Rule Curve' (Figure 2). This may be revised through the Dee Consultative Committee.

3.6 Cost Apportionment

The Apportionment Ratio agreed is that the Authority shall contribute 100% of the costs as detailed in Schedule 4.

3.7 Other Relevant Matters

3.7.1 The Undertaker shall consult the Authority before varying the management of any land if that variation involves any matter which is the subject of this Agreement.

3.7.2 Any information which the Authority may acquire relating to pollution incidents which could adversely affect the operation of the Poulton intake or the quality of water abstracted is to be notified to the Undertaker without delay.

3.7.3 The General Directions allow considerable flexibility for the sharing of regulation release requirements between Llyn Celyn and Llyn Brenig, and for the phasing of regulation releases from Llyn Celyn into Llyn Tegid. In specifying to the Undertaker the advance provisional 7 day requirements for such releases, the Authority will consult with local nominated officers of the Undertaker and will take into account, so far as is reasonable and practicable, the Undertaker's objective of maximising hydropower income and minimising additional manning costs.

3.7.4 Flexible operation of the compensation waters from Alwen reservoir and Llyn Brenig, in accordance with control rules agreed by the Dee Consultative Group, shall be at the discretion of the Undertaker, after prior notification to a local nominated officer of the Authority.

3.7.5 Occasional regulation releases from Alwen reservoir shall be subject to specific approval by a local nominated officer of the Undertaker and will generally be in substitution for regulation releases which would otherwise have been made from Llyn Brenig.

SCHEDULE 4 - FINANCIAL PROVISIONS

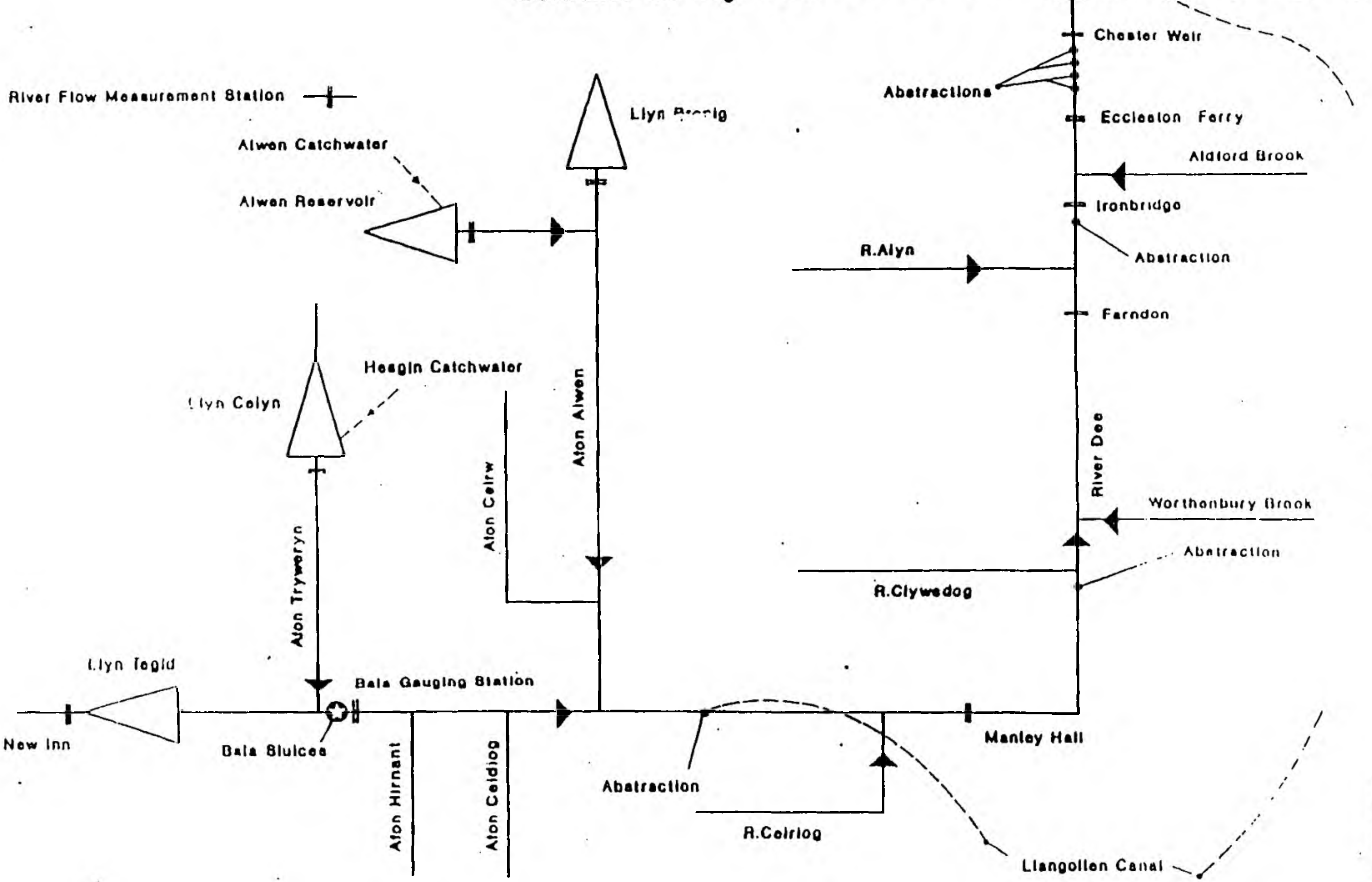
4.1 Payments Dates

Payments will be made by the Authority to the Undertaker in respect of each relevant financial year commencing 1 April as follows:-

4.1.1 Four quarterly Provisional Payments on 1 July, 1 October, 1 January and 31 March in that year.

4.1.2 Final Payment on whichever day shall be the later of 1 July following the end of the relevant year or thirty days after receipt by the Authority of the Statement of Final Total referred to in clause 4.4 below.

Sketch of System



DEE REGULATION SCHEME

Figure

BRIEFING NOTE FOR NRA STAFF
RIVER DEE FLOW REGIME
WATER QUALITY IMPACTS

1. Current Situation

The flow regime of the River Dee is currently managed to support lowland abstractions by 4 water companies (North West Water, Welsh Water, Chester Waterworks Co and Wrexham and East Denbighshire Water Co). Flows in the river are regulated at Eccleston Ferry and releases are made from upland reservoirs to ensure that the needs for potable and industrial supplies (9.5 cumecs) are satisfied whilst maintaining a residual flow to the estuary over Chester Weir of 4.2 cumecs.

The main River Dee is of high quality being within Class 1A from its source to the confluence with the Clywedog at Wrexham and Class 1B downstream to Chester Weir. The main tributaries downstream of Llangollen are of variable quality (e.g. Alyn class 2, Clywedog class 3, Worthenbury Brook class 3, Pulford Brook class 3, Aldford Brook class 3, Ceiriog class 1A). Nevertheless, a number of pollution incidents occur within the catchment from agricultural activities, sewage discharges and industrial sites. The industrial sites at Ruabon, Chirk, Wrexham and Mold have historically been the source of a number of problems associated with deterioration of effluents or more commonly acute spillages.

Since a major incident in 1984 when phenol contaminated water was abstracted and passed into public supply, a very sophisticated and comprehensive monitoring scheme has been implemented and progressively enhanced to provide protection to water abstractions, particularly as limitations in storage capacity at the intakes requires that periods of intake closure are minimised. The monitoring procedure which currently involves daily sampling at 5 main river and 2 tributary (Alyn and Clywedog) locations is to be enhanced to a twice daily frequency. This is supplemented by a River Monitoring Station at Manley Hall (NRA operated) and a very similar Intake Protection Station at Huntington (North West Water operated) with proposals for a further station at Poulton.

The monitoring procedures are supported by comprehensive incident management procedures which are co-ordinated by the Dee Steering Committee which includes all 4 water companies and the NRA.

2. Proposed Changes

Various changes have been proposed to further reduce the risk of polluted water being abstracted from the Dee and to ensure security of supplies by minimising impacts on river water quality. These changes include the following:

(i) relocation of public water supply abstraction points from the lower Dee to a point near Llangollen, upstream of many of the potential sources of pollution.

(ii) piping of effluents and drainage from high risk areas to locations downstream of existing discharge points.

(iii) additional pollution prevention measures including increased 'conventional' pollution prevention by increased frequency of inspections and sampling; introduction of new regulations for farm and industrial sites; further development of river monitoring/intake protection systems; protection zone powers.

Each of these 3 main options are considered.

3. <u>Relocation of Abstraction Points Upstream</u>

The relocation of the current 7 abstraction points to a combined abstraction point at Llangollen offers the following <u>advantages</u> in terms of quality and security of abstracted water:

(i) the abstraction point is upstream of many sites and tributaries which have been the sources of pollution incidents.

(ii) the extent of monitoring to protect the quality of abstracted water could be rationalised considerably.

(iii) shut-downs for reasons of poor water quality would be reduced.

(iv) shut-downs caused by flow reversal and tidal effects would not be necessary.

(v) the requirement for Section ~~111~~ 93 powers (Water Resources Act, 1991) to establish protection zones would be unlikely.

<u>Disadvantages or potential problem areas</u> include the following:

(i) to optimise the benefits from an upstream abstraction point requires relocation of <u>all</u> the existing intakes; retention of a single abstraction point at any of the existing locations would seriously undermine many of the above advantages, assuming that the current or anticipated level of protection for any retained abstraction points will be required.

(ii) the considerable reduction in flow in the Dee downstream of Llangollen from removal of regulation water will necessitate a review of consent conditions for all main river discharges. In view of the existing application of minimum standards, the only discharge significantly affected in this way will be that from Five Fords Sewage Treatment Works for which it is estimated that consent revisions from BOD 50, Suspended Solids 60 and Ammonia 16 to Standards of 36/60/8 would be necessary to maintain downstream river quality in Class 1B. Substantial investment would be required to achieve this.

(iii) Other discharges will not require substantial changes in sanitary determinand consent limits but reduced dilution may make the impact of nutrients more significant and provide conditions suitable for proliferation of algae. Algal growth would be favoured by slower flows and higher temperatures due to increased retention/travel time. In turn, algal activity may lead to diurnal variations in pH and dissolved oxygen and potential risks to fisheries.

(iv) Discharges such as that from Monsanto may be more significant by virtue of lower dilutions for trace organic pollutants. Whereas the consequences of these for potable supply and taste/odour problems will no longer be an important consideration, other problems such as tainting of fish flesh or deterrents to fish movement may become significant.

(v) The consequences of incidents from discharges or spillages within the catchment may be more serious due to lower dilution in the Dee. Extent, degree and duration of impacts on fisheries in particular may be increased. Levels of detection of incidents may be reduced by reductions from the current levels of monitoring.

(vi) The impacts of tributaries with quality problems on the Dee may be more pronounced leading to possible downgradings in main river quality unless major investment of resources on catchment campaign activities is undertaken over an extended period of time.

(vii) The aesthetic impact of effluent discharges may be increased requiring further tightening of quality standards.

(viii) The reduction in residual flow to the estuary may lead to greater and more prolonged saline intrusion into the lower catchment and changes in ecological status and aesthetic quality. Also, fish kills have occurred in the estuary in the past when residual flows have fallen below 4.2 cumecs and any flow regime that increases the frequency of such events could exacerbate this problem.

(ix) substantial costs would be incurred in relocation of an intake monitoring station upstream of Llangollen although this would be a short term effect with cost savings ultimately being achieved from rationalisation of the current system.

(x) the presence of pollution sources upstream of the proposed abstraction point would mean that there would still remain risks to the quality and security of supplies, albeit that these may be reduced from current levels.

(xi) Unless included in the scheme, the quality and security of supply for the abstraction by the Milk Marketing Board at Wrexham would be reduced.

4. <u>Diversion of Effluents to Points downstream of Water Intakes</u>

It has been suggested that effluents and drainage from sites historically the sources of pollution incidents may be diverted to discharge downstream of existing abstraction points. This alternative scheme may be cheaper, more feasible technically and address many of the concerns about risks to water supplies.

For example it has been suggested that the effluents from Monsanto and Five Fords STW together with drainage from Wrexham Industrial Estate (i.e the Red Wither Brook and Is y Coed Drain), Chirk (Afon Bradley) and Synthite at Mold may remove the primary sources of risk.

Such a proposal raises a number of fundamental issues:

(i) The combined or separate discharges would have to discharge to the Dee estuary which already exceeds environmental quality standards for ammonia and certain metals and which may be prone to fish kills during periods of natural freshwater flow during drought and summer conditions.

(ii) The enforcement of a combined discharge from a number of sources would be complex at the least, if even feasible.

(iii) A number of pollution sources and risks would remain within the catchment e.g. farms, waste disposal sites, other industrial sites etc and no diminution of monitoring effort could be made without corresponding increases in risk to water supplies.

(iv) It is not known how such a scheme could be funded and it is unlikely that dischargers or operators of high risk 'dry' sites would be prepared to fund such a scheme.

An alternative proposal for storage of effluents for release when river conditions and closure of intakes allow presents considerable potential control and enforcement difficulties, additional risks of spillages or problems from malfunction or maloperation and does nothing to remove risks from the catchment. Furthermore, such a system would require very regular programmed shut-downs which are expensive, and would experience storage difficulties during extended low flow conditions when discharges may not be allowed. Excessive storage capacity for large areas such as Wrexham Industrial Estate would probably eliminate this as an option.

5. Retention/Enhancement of Current Arrangements

Paradoxically the perception that the Dee is a polluted river and that there is unacceptable risk to water intakes results from the success of monitoring and detection systems in identifying changes in quality that are not even monitored on many other rivers used for potable supply. Similarly, quality expectations of the Dee supplies are high and the abstractors quite properly take every possible precaution to avoid supplying water which either breaches the EC Drinking Water Directive or is in any way aesthetically impaired by virtue of its taste, odour or general organoleptic properties. Elsewhere in the UK for example, levels of herbicides in abstracted water are regularly passed to consumers above those that would lead to closure of intakes on the River Dee. The abstractors have become conditioned by their experiences in 1984 and the emergence of highly critical consumers and drinking water quality developing as a high profile local issue.

Despite the perception of the Dee and indeed the continuing high level of incidents there have been very few occasions when it has been necessary to shut down abstractions; invariably the recorded shut-downs have been precautionary in nature or resulting from public awareness of incidents. In fact, the level of protection to the Dee intakes is greater than for most abstractions in the UK and this has recently been or is being considerably enhanced by the following:

(i) a 60% increase in Pollution Control resources within the Dee Catchment enabling greater effort to be made on inspections, enforcement etc.

(ii) enhancement of the Manley Hall River Protection Station to increase reliability, improve telemetry and monitor additional high risk determinands e.g. formaldehyde.

(iii) the addition of 3 further sites to the daily 'Deesit' monitoring and the proposed doubling up of the monitoring run to reduce the "windows" through which a pollutant could pass undetected.

(iv) implementation of the Farm Waste and Oil Storage Regulations as a positive step forward in reducing the threat from agricultural pollution.

(v) development of the application for Section 111 Protection Zone powers thereby ultimately provide controls on levels of risk within the Catchment.

(vi) improvements to high risk sites such as Monsanto (£5 million over the last 3 years).

(vii) thorough appraisal of new developments within the catchment. eg.waste disposal sites.

It is noted that for hydrological reasons the provision of bankside storage is perceived as the best solution to the problems of the Dee. The potential impacts of the alternative proposals and the potential benefits to the current operating regime from the enhancement of pollution prevention measures leads this to being the logical conclusion too on water quality grounds.

6. Summary

Whereas an exhaustive environmental impact assessment of each option proposed together with costings evaluation would be required to provide definitive views on the optimum solution for security of water supplies from the Dee, there are powerful arguments for retention of the status quo. Considerable enhancement of the protection systems has occurred since inception of the Dee Protection Scheme in 1984 and current developments will continue this trend. There can be no absolute guarantees of river quality or elimination of all risks and the provision of bankside storage at each abstraction point is viewed as the most logical and practicable measure that should be pursued.

S J Brown
Divisional Pollution Control Manager
(KVH/pc2112)

Perceived and Measured Impacts of Dee Regulation

Fisheries

1) Temperature Change

i) Since regulation a reduction of temperature has been shown to have taken place within the system which has likely had damaging consequences for coarse fish populations in the lower river. Species affected include roach, perch, bream and pike with a marked decrease in abundance. Dace have benefitted from the change. Likely reason are slower growth rate of juveniles, leading to poor overwintering recruitment. Complicated circumstances apply in the lower Dee with various factors involved. (See BP Hodgson PhD). Problems exacerbated by higher volumes, faster run-off and gradient profile of the Dee.

ii) Faster run-off of colder water probably reduces catchability of salmonids and coarse fish. Receive complaints on this issue.

iii) No temperature targets for releases water presently apply and no detailed assessment on temperature variations between respective draw-off points in the reservoirs have been undertaken. Needs looking at.

2) Acidity increases in the Catchment

The Alwen catchment is acidic and the Brenig catchment is fairly neutral. Since releases have taken place from Brenig, problems have occurred with increased acidity down the river Alwen as a result of natural overspill from Alwen when Brenig is still refilling. This is because Brenig is a slow refill reservoir. This has caused reduced juvenile salmonid recruitment on a system which was previously the best spawning tributary on the Dee.This problem is being investigated and discussions are taking place with Welsh Water on possible improvements to the system.

3) Reduced Summer Spates

i) The steady summer flows are believed to be reducing the activity of salmon once they enter the river. This is reducing their availability for capture by anglers. Radiotracking has indicated this phenomena. With the increased volume of water in the river it is also believed that it takes larger spates to actually activate the fish to move. At present fish come in, are more available for capture in first 30 days, then they drop into deep water and are not active (and relatively unavailable to the anglers) until just prior to spawning when they move and can be caught again.

ii) More stable flows have reduced flooding incidents and it is believed that this has increased siltation in the catchment with possible damaging consequences for reduced spawning success in both salmonids and dace.

iii) From radiotracking work there are indications that movement through the tideway by salmonids are more restricted with the steady summer flows. Previously small summer floods could well have assisted upstream movement in this area of river.

4) Higher Flows exacerbated by flood embankments on the Cheshire Plain

The combination has produced a harsh terrain for coarse fish in the lower catchment. There are few tributaries and therefore little sanctuary area for fish offstream. Habitat has been degraded by scouring and colder conditions which probably restricts aquatic plant growth which in turn reduces microhabitats essential as food webs for fish.

5) High Flows on the River Tryweryn

As Llyn Celyn is fast refill it is the work-horse of the system for regulation. The heavy releases have scoured the tributary so there is now minimal spawning gravels for salmonids and the river as a trout fishery has been spoilt. Prior to regulation, the Tryweryn as a whole (Much lost under the reservoir) was a major spawning tributary. Minimal production now.

6) Bala Lake (Llyn Tegid) Levels

Controlled levels of Bala Lake have meant that spawning territory for pike and other coarse fish has become less available at critical times of year. This has damaged recruitment.

Conservation

i) There has been a reported reduction in distribution since 1984 of a rare stonefly (Isogenus nubecula) in the lower river. Report recently prepared on this. (See N. Milner EAU.)

ii) On account of the increased flows on the river following regulation, there has been an on-going commitment by flood defence to protect banks with stone walling. This has raised landscape and conservation concerns in the areas of the Llandderfel Loops and again down at Bangor-on Dee.

Aquatic Ecology

This is very much interelated with the fisheries. See my PhD for some of the detail on how the lower Dee has been affected.

Recreation

i) Controlled releases on the River Tryweryn have benefitted canoeing interests but changes to the way water is released to maximize revenue from electricity could impact on the canoeing interests. Discussions still on going with Welsh Water.

ii) There are conflicts between canoists and anglers on how water should be used (ie Special release volumes.)

Navigation

Although there is limited proof and taking into account that the Dee estuary has been silting up for years. There is an indication that the canalised section has silted up faster since regulation on account of the more stable flows. I can remember much deeper netting stations in this section when I came to the Authority back in 1974. This has impeded navigation of smaller craft up to Chester. Large vessels have not been able to get up this far for many years.

Suggested Reports

Regulation of the River Dee. Allan Lambert (1988)
Juvenile Monitoring Reports NRA
Bibliography of the River Dee. Howard Pearce and Ken O'Hara
River Corridor Surveys.(Contact Bryan Jones, Caernarfon)
The Effects of Flow Reduction in the River Dee on aquatic environments.
The Ecology and Management of the Coarse Fisheries Populations of the Lower Welsh Dee. B.P.Hodgson. PhD Thesis 1993
Dee Salmon Monitoring Programme (Ian Davidson, Mold)
Salmon Radiotracking on the River Dee (In prep Bill Purvis Buckley/Mold)

I hope this information is useful. Brian.

RIVER DEE - BRIEFING NOTE FOR NRA STAFF

WATER RESOURCES VIEWPOINT

1. BACKGROUND

A proposal has been made to move the public water supply abstraction points of the lower Dee some 45 km upstream to a point near Llangollen.

This has a number of major implications for the future of water resources and water quality in the Dee catchment.

This note outlines the implications of this proposal on NRA interests.

2. EFFECTS ON PRESENT YIELD OF THE DEE SYSTEM

EXISTING YIELD AND REGULATION
The current yield of the system is 14.3 cumecs. This comprises 9.3 cumecs licensed, 0.8 cumecs unlicensed (i.e spare yield) and the maintenance of a residual flow of 4.2 cumecs over Chester Weir.

EXISTING YIELD AND REGULATION
Chester Weir is currently the only point where a flow has to be maintained. Therefore, a flow of about 14 cumecs has to be maintained in the lower Dee to satisfy both abstractors and the maintained flow condition. In spate, this volume naturally occurs. At other times, the natural flow is supplemented by regulation releases from the upstream reservoirs.

EFFECTS OF PROPOSAL
An additional control point would have to be established at Llangollen. A flow of at least 9.3 cumecs would need to be maintained to support the abstraction alone. A higher figure would need to be maintained in practice to satisfy the in-river needs below the abstraction. A figure of 3 cumecs was the maintained flow required before Llyn Celyn was built.

With the existing situation, the whole of the Dee catchment naturally contributes to the flow at Chester. If the abstraction is moved to Llangollen, only the catchment area to that point can contribute. Thus the abstractions will require a greater amount of support from the regulating reservoirs since less 'natural' flow is available at Llangollen. It is estimated that the yield available for abstraction will fall to 9.5 cumecs. This is roughly equivalent to the existing licensed volume, and effectively leaves no spare yield in the system.

3. ESTIMATED COSTS

The cost of piping the abstraction from Llangollen is estimated at £30 million, to which can be added substantial operating costs (eg pumping).

The reduced yield will bring forward the time when additional resources have to made available by about 6 years. These are discussed in 6. below.

4. NRA ROLE

The Water Act 1989 puts the responsibility for making adequate resources available for Public Water Supply on the Water Companies. (Section 125(2)).

The same Act gives the NRA the role of securing the proper use of water resources. (Section 125(1b)). The view is taken that the proposal does NOT constitute the proper use of resources. The Dee yield is supported by expensive (to the NRA) regulating reservoirs. Securing powers for their construction was not easy (eg Treweryn). This proposal seeks to reduce the water resources available with no benefit to the water environment, and for no good water resource reason.

The NRA may have a role in providing resources (see 6. below). It does NOT have a role in providing pipelines for its abstractors for the conveyance of water from their abstraction. This would be for the abstractors to provide. It is considered that the NRA has no powers to make such a provision.

It would be for the abstractors to promote the scheme. They would have to revoke their licences and apply for a new abstraction licence, since NRA cannot apply for a licence for a third party.

If the abstractors did apply for a licence to move the abstraction to Llangollen, the NRA should refuse the licence, since it is not the proper use of water resources, i.e. moving the abstraction causes a reduction in the available yield of a major resource scheme and for which NRA currently pays around £2.6 million per year under the Section 126 agreement - and for no good water resources reason.

5. FUTURE DEMAND FORECASTS

The public water supply abstractions are forecast to exceed their current licensed volumes by 2002. The yield of the Dee system would be exceeded in 2008 under existing conditions. (Details are given in the report "Review of Major Public Water Supply Abstractions from the River Dee" (1991), NRA Welsh Region).

6. MEETING FUTURE DEMANDS

When the Dee Regulation was approved by statute, consideration was given to how future demands would be met. These proposals are:

1. Catchwaters from the Conwy and Arenig catchment to Llyn Celyn. This also requires the spillway capacity to be enlarged to meet ICE recommendations for spillway design.
2. Pumping from the Dee in high flows to Llyn Brenig.
3. Transfer of water to Llyn Brenig from Llyn Celyn and Afon Alwen.
4. Increase storage of Brenig by raising the dam.
5. Construct new regulating reservoirs in the Twrch and Hirnant valleys within the Dee catchment.

All these are high cost schemes with funding falling, it is believed, to the NRA. The NRA would promote the scheme, bear the cost and then recover those costs across all the abstractors.

Any reduction in current yield would bring forward the date when these schemes have to be introduced from, say 2008 to 2002. Bearing in mind that 2002 is only 11 years ahead, and it can easily take this long to promote and construct such a scheme, then the provision of new resources would have to go hand in hand with the construction of the pipeline.

7. ALTERNATIVES TO PROTECT EXISTING ABSTRACTIONS

a. Pipe effluents below lowest abstraction.
   This is not costed, but since the volume is only 10% of the abstractions, it is unlikely to exceed £10 million. This proposal is limited to those effluents which are known to cause pollution problems and which can be gathered into a single pipe.

b. Water Companies protect themselves by, for example, providing adequate bankside storage to maintain supplies during periods when river intakes are closed.

c. Dischargers provide storage of effluent which is monitored prior to discharge to be released when river conditions and closure of intakes allow. However this only deals with the point sources of effluent and does not allow for diffuse inputs or 'accidents' at other sites.

Whatever the solution, it is the water companies problem to ensure that their supplies are of suitable quality. The NRA cannot guarantee quality, nor can it prevent accidental or deliberate pollutions.

8. SUMMARY

* A piped abstraction from Llangollen is a very wasteful use of an expensive resource.

* Such an abstraction would require very large expenditure, possibly by the NRA, to bring forward additional resource schemes, a cost which would be passed onto all abstractors for the benefit of one.

* It is not the NRA's duty to safeguard the quality of the water abstracted by others.

* Our understanding is that privately the proposal is not wanted by the abstractors and cannot be justified in any way on water resources grounds.

* The use of water resources in this way could be regarded as a breach of our statutory duty to secure the proper use of water resources.

* If North West Water wish to move their abstraction to Llangollen, that is a matter for them to pursue. It is not good water resource practice, since the resultant loss of yield will require additional schemes designed to meet future demands to be brought forward to satisfy an unnecessary reduction in the present yield.

* Promotion of any scheme in that part of Wales will meet exceedingly stiff opposition. Politically it will be exceedingly difficult. A public enquiry is inevitable, and the Inspector would need to be satisfied that existing resources were being fully utilised. This would be difficult to uphold, and indeed NRA should not support the application.

* A lowland abstraction where there is no bankside storage to allow pollution incidents to pass through without causing supply disruption

is, to my mind, naive. This seems to be the preferred solution and would have no detriment on water resources.

J C Mosedale
17th September 1991

REGULATED RIVERS: RESEARCH AND MANAGEMENT, VOL. 2, 293–308 (1988)

REGULATION OF THE RIVER DEE

ALLAN LAMBERT

Water Manager, Northern Division, Welsh Water, Clwyd, CH7 6NQ, Wales

ABSTRACT

This paper discusses the interdisciplinary approach statutorily adopted for the management of the intensively regulated River Dee. The role of the Dee Consultative Committee is discussed and the procedures and methods for river regulation are described. Particular problems arise during severe droughts and a Conservation Rule Curve, using the aggregated storage of the two main reservoirs, has been devised to act as the trigger for optional initiation of water conservation measures. The social and environmental benefits of the integrated management scheme are demonstrated. Areas of conflict have been, and must continue to be, resolved by consultation, cooperation, and compromise.

KEY WORDS Integrated management Operating rules Consultative Committee

INTRODUCTION

The River Dee is a particularly appropriate example of an interdisciplinary approach to the management of regulated rivers. It is a multipurpose, multiuser system. The management strategy is continually updated and reviewed through a Statutory Consultative Committee, representing both river and abstraction interests, with substantial discretionary powers for flexible operation. The Dee Consultative Committee (DCC) is in many ways unique.

Publications relating to the Dee are very numerous; an annotated bibliography (Pearce and O'Hara, 1984) listing 879 reference sources was produced in 1984. Very few can be adequately described in a brief overview such as this. The first section of this paper contains a brief description of the River Dee, the development and uses of its regulating reservoirs, and the important influences of tidal action in the lower reaches. The second section outlines the development, objectives and functioning of the DCC, which could form an effective model for other regulated rivers. The third section covers the principles and practices of Dee regulation.

RIVER DEE REGULATION — A BRIEF DESCRIPTION

The source of the Dee lies in the Snowdonia National Park (Figure 1). The course and topography of the river valley and its tributaries were strongly influenced and modified by the glaciations which ended some 13000 years ago. The catchment area of 1816 km^2 to Chester Weir, at the head of the Estuary, ranges from impermeable Cambrian and Ordovician shales in the West, through Silurian to Carboniferous Limestone outcrop at Llangollen, through Coal Measures to thick boulder clay overlying the Triassic Sandstones of the Lower Dee valley. An appreciation of geology and geomorphology is most useful for understanding the peculiarities of natural river constraints, such as the wide variation in dry-weather flows of Lower Dee tributaries, or the substantial channel and floodplain routing effects in the flat beds of former interglacial lakes. Farmers in the Lower Dee floodplain can more readily appreciate the difficulty of preventing flooding completely when is is explained that they are living on the bed of a former lake with a narrow restricted outlet capable of passing only 12 mm of runoff per day when running full!

0886-9375/88/030293-16$08.00

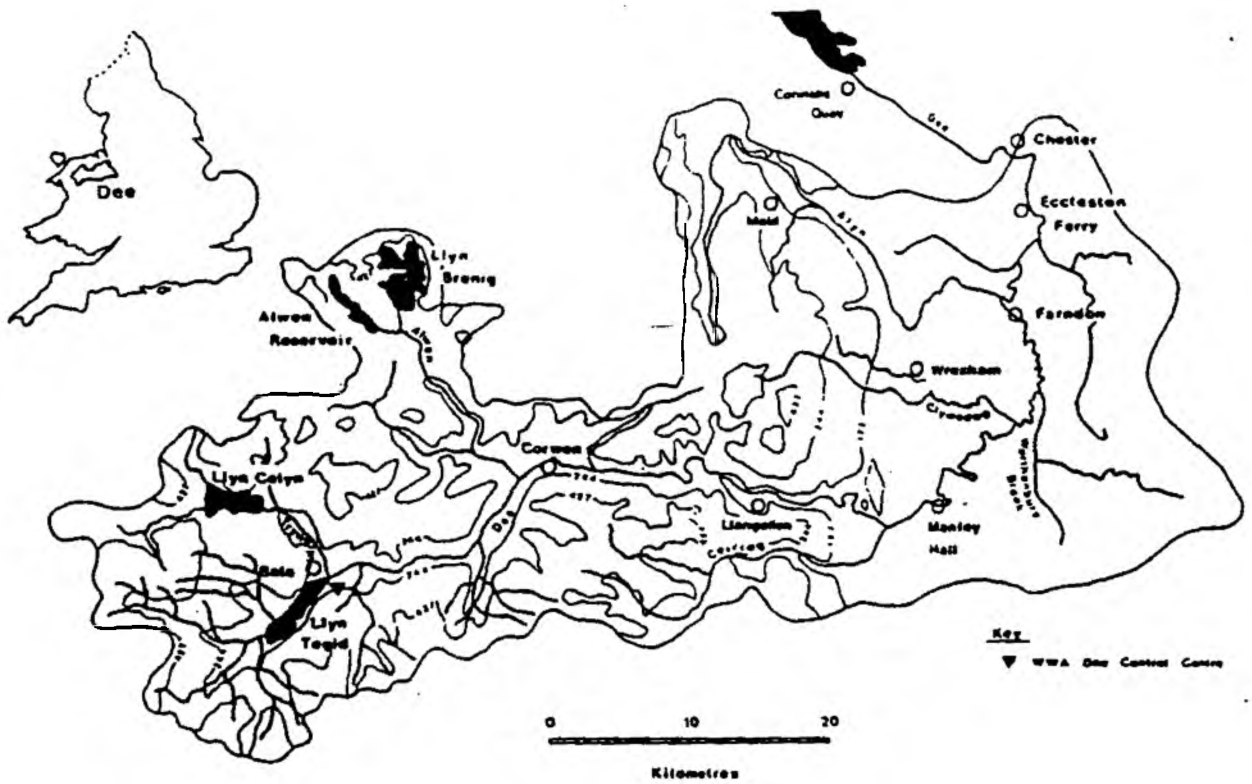


Figure 1. The Dee catchment and location map. Contours are in metres

Annual average rainfall varies from 2500 mm in the mountains above Bala to 600 mm near Chester. Typical annual evaporation is 450 mm, mainly in April to September. Natural annual average runoff to Chester Weir is 639 mm yr^{-1} (36·8 $m^3 s^{-1}$). Table I shows the storage and runoff characteristics of the three regulating reservoirs and Alwen Reservoir. Particularly notable are the wide variations in storage to average runoff ratio, expressed in days, and this parameter (which crudely measures speed of refill) has a marked effect on the conjunctive use management of the reservoirs. The four reservoirs control 17 per cent of the catchment area, and 35 per cent of the average runoff to Chester Weir.

1. Llyn Tegid is a natural lake up to 40 m deep. It was first used for river regulation in the early 1800s, when Telford constructed a simple adjustable weir at the outlet to permit controlled releases to sustain flows into the canal at Llangollen. In 1956, the present regulation facilities were constructed by lowering the lake outlet by approximately 2 m, building four vertical drop sluice gates, and diverting the Afon Tryweryn behind these gates. The works allow the top few metres of storage in Llyn Tegid to be used for flood control throughout the year, and for fine control of summer regulation releases to support continuous downstream abstractions (originally totalling some 2·5 m^3s^{-1}). Llyn Tegid is in the

Table I. Dee Regulation: facts and figures

Reservoir	Catchment Area (km^2)	Surface Area (ha)	Usable Capacity ($m^3 \times 10^6$)	Average Runoff $m^3 s^{-1}$	Average Runoff mm yr^{-1}	Capacity/Runoff Days
Llyn Celyn	60	325	81	3·1	1590	302
Llyn Tegid	262	400	18	11·5	1380	18
Llyn Brenig	22	370	60	0·62	884	1120
Alwen Res.	26	150	15	0·73	890	238

Snowdonia National Park, with substantial water-based recreation (sailing, boating, fishing) on and around Llyn Tegid, which is now an SSSI. These are aspects which had to be considered in the formulation of the operational control rules. The occasional flooding of the town of Bala due to high lake levels has been virtually eliminated by this scheme.

2. Llyn Celyn is a large regulating reservoir constructed in 1964, to be used conjunctively with Llyn Tegid, into which its releases flow. Much of the 81 million cubic metres storage was allocated to summer releases to support additional Dee abstractions of $3{\cdot}4\,m^3\,s^{-1}$, but substantial storage allocations were reserved for maintaining improved residual flows, flood storage, and special releases for fishery or other purposes. A 4 MW hydro-power station was built downstream of the dam, to generate power from regulation releases for sale to the National Electricity Grid. The combination of controlled discharges (generally $11\,m^3\,s^{-1}$) during daylight hours, down the steep rocky gradient of the Afon Tryweryn to Llyn Tegid, creates ideal conditions for canoe slalom, white water races, and rafting which have been substantially developed in the last decade.
3. To meet rising regional demands in the late 1970's, Llyn Brenig, the third large regulating reservoir was built in the headwaters of the Alwen tributary. This is a most unusual reservoir, in that its storage capacity represents three 3 years average runoff from its small catchment area, and in certain drought sequences (e.g. starting 1933) it would not fully refill for ten years. It is used conjunctively with Llyn Tegid and Llyn Celyn, and acts as a reserve for infrequent severe dry years such as 1984. With its construction, it was possible to raise the Dee abstraction by a further $3{\cdot}8\,m^3\,s^{-1}$, utilizing a valley which was originally scheduled for a small direct supply reservoir with a yield of only $0{\cdot}3\,m^3\,s^{-1}$. Llyn Brenig, which filled between 1975 and 1979, is extensively used for recreation, and has a useful but largely passive local role in flood peak mitigation.
4. Alwen Reservoir was built in the 1920's in the adjacent valley to Llyn Brenig, for a direct supply of $0{\cdot}5\,m^3\,s^{-1}$. It is not used for river regulation at present, but in 1979 Statutory Powers were obtained to flexibly combine the separate compensation waters from the two adjacent reservoirs, in a manner which substantially enhances the direct supply yield of Alwen whilst marginally improving the refill of Llyn Brenig. The Alwen compensation water is used for generating power for operation of the associated local treatment works, and proposals to generate hydropower from Llyn Brenig releases are under active consideration. Recreational activities on Alwen reservoir include fishing and water ski-ing.

The Dee catchment area of 655 km^2 upstream of Corwen is predominantly rural, with a population of approximately 10000 working in farming, forestry and tourism, with small light industrial estates at Bala and Corwen. The broad glaciated valley between Bala and Corwen contains much of the relatively scarce pasture so important to hill farmers, yet prone to flooding. A recent study of flood peaks at Corwen showed that, since 1964, flood control at the regulating reservoirs has doubled the return period of most floods (e.g. 1 in 5 year natural now occurs 1 in 10 years) and delayed the peaks sufficiently (see Figure 2(a)) to allow farmers to clear their stock from the flood plains on receipt of flood warnings issued by Welsh Water. Where partial flood control is exercised, it is also essential to have an effective flood warning scheme to maximize the economic benefits of flood damage reduction.

For its 43 km between Corwen and the Manley Hall gauging station (a compound crump weir built in 1969) the river is steep and confined within a narrow incised valley with negligible flood plain. Flood peaks from Corwen take about 5½ hours to move through this reach, without much change in hydrograph shape except the addition of tributary flows, notably from the Afon Ceiriog. The catchment area to Manley Hall is 1013 km^2. The upper part of this reach is rural; just upstream of the town of Llangollen, a major tourist attraction located in the centre of the reach, is Telford's original canal intake, at the Horseshoe Falls weir. The canal, now used only for recreational boating and conveyance of abstracted river water to supply, eventually leaves the Dee catchment south of Manley Hall. The lower part of this reach traverses the carboniferous strata, a locality which has been industrialized for many years, with abandoned mine workings, waste disposal sites, and chemical and other industries close to the river. Several of the more serious pollution incidents on the Dee in recent years have originated in this locality (Rushbrooke and Beaumont, 1986).

In the 60 km between Manley Hall and Chester Weir, the character of the river changes profoundly as it leaves the foothills, turns northwards and meanders through two broad flood plains, joined through a narrow channel at Farndon, before reaching Chester Weir (1816 km^2 catchment area) via a narrow post-glacial channel. A combination of local flood embankments and the effects of flood control at the regulating reservoirs has virtually eliminated summer flooding of adjoining pasture, but in winter the higher runoff and restricted outlet channel at Chester inevitably produce intermittent inundation of some areas of flood plain. All flood hydrographs from Manley Hall experience major attenuation from river-channel and flood plain storage. Figure 2(b) shows how the Manley Hall flood hydrograph of

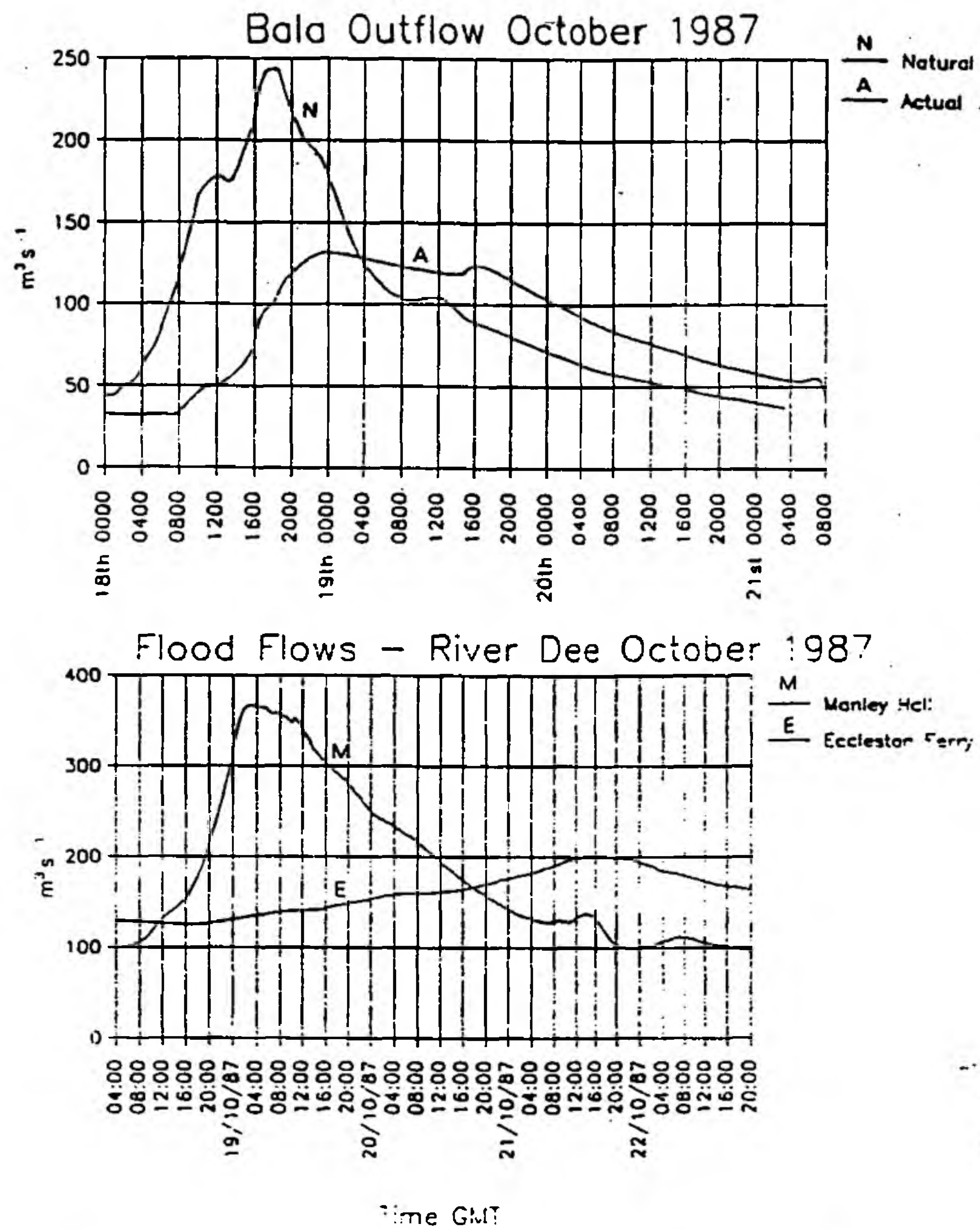


Figure 2 (a) Llyn Tegid (Bala Lake) outflow during the floods of October 1987; (b) River Dee floods of October 1987 hydrographs for Manley Hall (upstream) and Eccleston Ferry (downstream)

1987 (the highest for 20 years) was substantially modified in its passage through this reach. Within-bank spates also experience marked attenuation.

The east bank tributaries of the Lower Dee are predominantly rural, but the west bank tributaries include more substantial developments around Mold and Wrexham. The sewage effluent from these towns, and their associated industries, has been much less of a problem to the river environment since the Manley Hall regulated flow was raised from 2·9 $m^3 s^{-1}$ to 8 $m^3 s^{-1}$ after Llyn Celyn was built in the 1960s.

Chester Weir, originally built some 700 years ago on a natural sandstone outcrop, creates a significant backwater effect for the upstream reach in which most of the major water supply intakes are located; large abstractions by Northwest Water Authority leave the catchment near here. Normally, Chester Weir is the limit for penetration of saline water up-river during tides, either because the maximum tide height does not exceed Chester Weir level, or because of high freshwater flows. At higher tides with low freshwater flows, excess saline penetration over Chester Weir can be limited by provision of appropriate residual flows.

However, tide heights regularly exceed Chester Weir crest level, and frequently cause strong (up to 60 $m^3 s^{-1}$) reversal of flows in the 20 km reach from Chester to Farndon and beyond. Two-way flows, with temporary river level variations of a metre or more in 12 hours, will typically occur for 10 day periods in summer at regulated flows. These extreme unsteady hydraulic conditions cause obvious problems for hydrometric measurement, real-time control of regulation releases, and prediction of times of travel.

The correct management of regulation releases during these tidal periods is crucial, not least for migratory fisheries, as incoming salmon generally move up the canalized section of the estuary during these high tide sequences. If the residual flow is insufficient to safeguard fish between tides in the shallow water downstream of Chester Weir (which also receives the Chester Sewage Works effluent), there will be major fish kills. Such fish kills occurred in most summers before Llyn Celyn releases generally improved the residual flows over Chester Weir, but without skilful management of regulation releases the problem can recur, particularly during the grilse run each July, and during droughts such as 1976 and 1984.

Between Chester and Connahs Quay, the tidal Dee was straightened and embanked as part of a major land reclamation programme over 200 years ago. Tidal range in the main estuary is 6 m, but published (Astronomical) tide tables forecasts of high tide are regularly exceeded by up to 0·7 metres when low pressure atmospheric systems pass overhead, and occasionally by up to 1·8 metres under extreme surge conditions. During neap tide sequences, there are no tidal effects in the canalized reach, which conveys the Dee residual flow to the main estuary in a shallow sandy meandering channel. At other times, a spectacular bore moves up the canalized reach until it breaks on Chester Weir.

Observed tide heights at Chester are the result of complex inter-relationships between tide in the estuary and freshwater flow. The height and time of peak tide at Chester is crucial to the hydraulic conditions in the Farndon to Chester reach of the Dee over the subsequent 12 hours, but the meteorological conditions and freshwater flows which affect the Chester Weir tide cannot generally be forecast accurately more than 24 hours ahead. By comparison, it takes up to two days for low-flow regulation releases from Llyn Tegid to reach Chester Weir.

RIVER REGULATION MANAGEMENT BY CONSULTATIVE COMMITTEE

There are five regulated rivers (Dee, Clwyd, Aled, Gwrfrai, and Dwyfor) managed by Northern Division of Welsh Water, but the Dee is the largest and the best known nationally and internationally. The overall management strategy for this multipurpose system (now using three major reservoirs) has been developed over a 30 year period, and is continually refined and adjusted, through a Statutory Consultative Committee representing both river and abstraction interests.

The existence of the Dee Consultative Committee, together with the substantial degree of flexibility in regulation mehods permitted by Section 9 of the 1973 Dee and Clywd River Authority Act (see Appendix 1), has undoubtedly provided an effective management framework for the resolution of problems. Some of these are described in this paper. Experience teaches us that the problems of the future will differ from those of the past and present, because of gradually changing social and environmental constraints, or because of exceptional events or emergencies involving drought, flood, pollution, or perceived mismanagement.

Intensive regulation of the Dee for major regional water supply abstractions (by Northwest and Welsh Water Authorities, two Water Companies, and the British Waterways Board) is undertaken with due regard to safeguarding fisheries and flood mitigation, and other interests such as recreation and hydropower generation. Policies and practices have been formulated by constructive discussion, with recognition of constraints and resolution of areas of conflict by mutual understanding and compromise. Strategies for droughts, floods, special releases, and emergencies are pre-planned as far as possible. There is also provision for rapid decision-making on those occasions when short-term tactical actions are essential.

However, there are many actual and potential problems in regulating rivers such as the Dee. The legal framework of the DCRA Act 1973 allows the DCC and Welsh Water (which operates the day-to-day river regulation) to make almost all the important decisions necessary to manage the river effectively. It also places unequivocal responsibility on these bodies to act at all times in a professional, evenhanded, and competant manner. If mistakes or undue bias should occur, there is generally no refuge in blaming others.

PROCEDURES FOR RIVER REGULATION

The detailed procedures for regulating the Dee are incorporated in a document entitled the 'General Directions' (Welsh Water, 1987), consisting of 'Normal General Directions' and 'Drought General Directions'. The DCC has the function of assisting Welsh Water in the formulation of General Directions, and the duty of commenting to Welsh Water upon any such General Directions as are proposed or issued by Welsh Water. Welsh Water shall, in preparing any such Directions, consult the DCC and have regard to any views expressed by the DCC with respect to such Directions. Drought General Directions are subject to the reasonable approval of each of the bodies represented on the DCC, with provision for differences and disputes to be referred to arbitration. The fact that arbitration has never yet been required, or even considered, despite severe droughts in 1975/6 and 1984, reflects the tradition of co-operation and compromise which is expected of those officers and members who represent different interests on the DCC.

It is more than 36 years since the first Statutory Consultative Committee (the Bala Lake CC) was formed under the Dee and Clwyd River Board Act 1951. Their powers were very limited powers compared to those now available to the DCC. Statutory Consultative Committees on the Dee have existed throughout the major national reorganizations of English/Welsh Water Services in 1964 (formation of River Authorities) and 1974 (formation of Regional Water Authorities), during which the operational and administrative units involved have undergone numerous changes. At the time of writing (November 1987) further major changes involving privatization of RWA's and the formation of a National Rivers Authority are under advanced consideration. Proposals for possible 'operating agreements' for water resources systems are also being discussed.

Continuity of management on the Dee has been readily accommodated by ensuring appropriate representation of new organizations on a reconstituted Consultative Committee whenever major reorganization of Water Services occurs. In this manner, privatization and/or NRA formation can also be accommodated. The success of the DCC was recognized internationally in 1985 when a working party from Norway, charged with the task of examining and evaluating existing methods worldwide of achieving 'flexible manoeuvring' of regulated rivers subject to multipurpose development, recommended the DCC as a role model for use in Norway. They commissioned a seminar paper (Lambert, 1985) for more detailed consideration by interested parties. In the Author's view, from experience in the U.K. and abroad, the DCC is a role model which could be used successfully for resolution of problems in many multipurpose river regulation systems.

However, a word of caution here would not be misplaced. The DCC (or any clones) can succeed only if the representatives sitting on such committees clearly recognize that:

1. It is often the river and its environment which suffer most if there is ineffective management arising from failure to compromise between various interests.
2. The major interest (generally water supply in England and Wales, Hydropower or irrigation internationally) can often make substantial accommodation arrangements for other interests in most years, and in most seasons, without significantly compromising its main objective.
3. No-one, however experienced, knows everything about every aspect of a regulated river. Effective management is a team effort, based on action-learning. Representatives must be prepared to listen and learn, and often their hardest task will be to educate colleagues in their own organizations who suffer from 'tunnel vision', for whatever reason.
4. Representatives must be sufficiently senior to commit their own organizations to particular courses of action, jointly agreed after due consideration.
5. River regulation systems are real-time systems in which operations and research must continually progress together.

Irrespective of the commitment and goodwill of Consultative Committee representatives, persistent tension and disagreement are probably unavoidable if the resources at their disposal are clearly inadequate to meet truly irreconcilable objectives, or the objectives are not defined with reasonable clarity and priority. The DCRA Act 1973 not only defines objectives, but refers to a design drought of severity estimated to occur once in one hundred years. This indirectly ensures that licensed abstractions will not be permitted to outstrip the operational yield of the regulating storage provided. It is also worth noting that, as most instructions will eventually be specified in terms of levels (river/reservoir) and storage or discharge, it is essential that the procedures for any particular river do not require a standard of hydrometric measurement/transmission/forecasting/control which is either unavailabe or unattainable.

It should also be understood that routine day-to-day management of river regulation systems is rarely carried out by water resources engineers, hydrologists, or scientists. More frequently the releases are controlled by technicians, supervisors, or manual operatives, in accordance with reservoir control rules and instructions which must be specified in an unambiguous and user-friendly manner. Whatever their background and training, the operations personnel in day-to-day control can acquire, through observation and experience, a 'feel' for the natural constraints of the system (e.g. times of travel) which is invaluable, for example if the telemetry system malfunctions during flood conditions. During emergencies, experience is a precious commodity and should not be undervalued. In Welsh Water, the three senior personnel closely associated with Dee regulation have, respectively, 22, 17, and 13 years operational experience.

RIVER REGULATION METHODOLOGY

In the course of designing and refining 'in-house' the operational control rules used in the General Directions, a general methodology (the ten component method) has been derived Lambert (in prep.) and applied to a wide variety of water resource management situations in North Wales and elsewhere. Figures 3 to 6 show some of the principle control rules derived by this method and used in the Dee General Directions. Llyn Celyn (Figure 3) is the workhorse of the system, where the uses of low-flow regulation, flood control, and hydropower generation must be reconciled. Llyn Tegid (Figure 4), sited downstream of Llyn Celyn, operates on a finely balanced bandwidth control which has due regard to amenity whilst providing temporary re-usable storage for variable inflows in summer, and major short-term flood detention storage throughout the year.

Llyn Brenig (Figure 5) is a large, slow-refilling storage reserved mainly for severe drought years, but nevertheless the control rules also make effective use of the seasonal inflows in more normal years. Figure 6, the System Conservation Rule Curve, employs the principle of Aggregated Storage of the two largest reservoirs (Llyn Celyn and Llyn Brenig) as the basis for assisting decisions on when to switch from 'Normal' to 'Drought' General Directions, and vice versa.

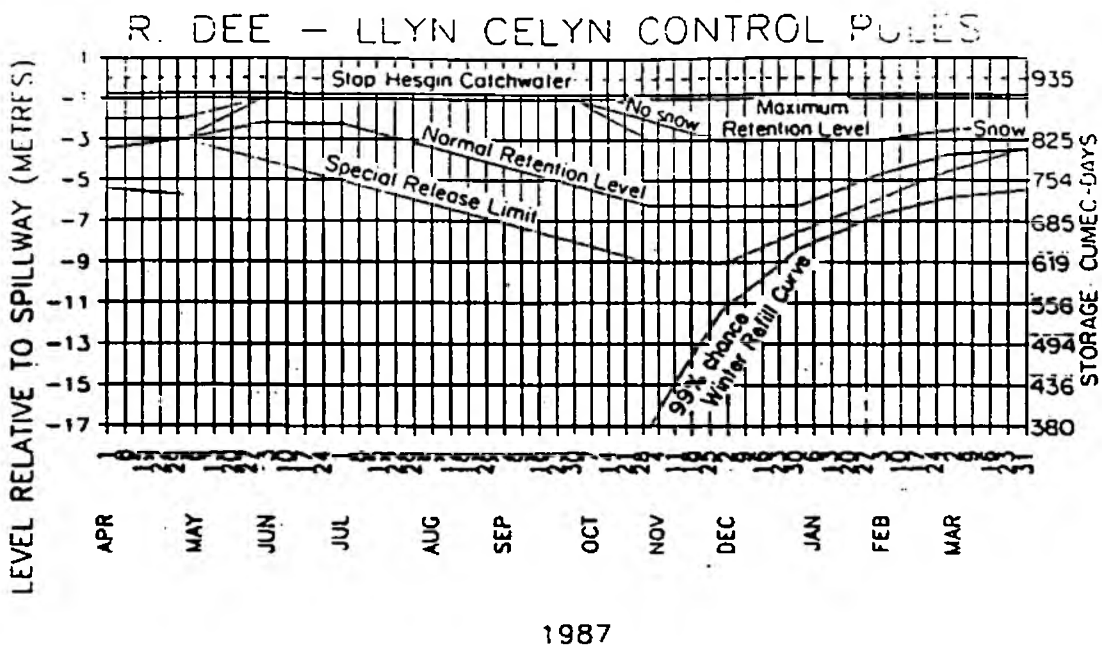


Figure 3. Llyn Celyn control rules for 1987

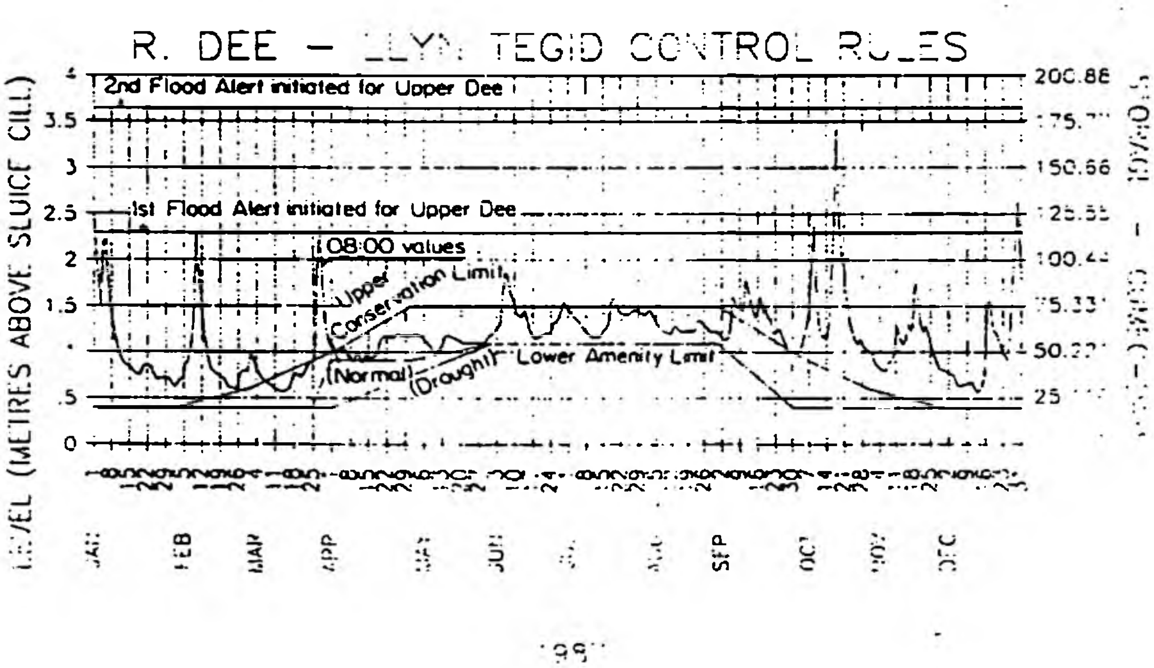


Figure 4 Llyn Tegid control rules for 1987

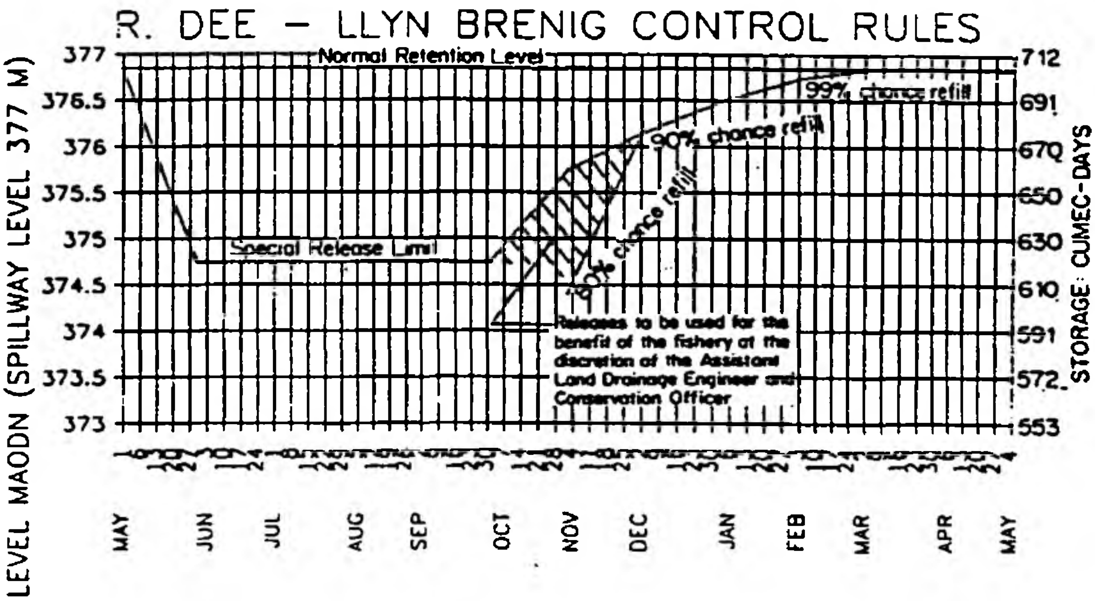


Figure 5. Llyn Brenig control rules for 1987

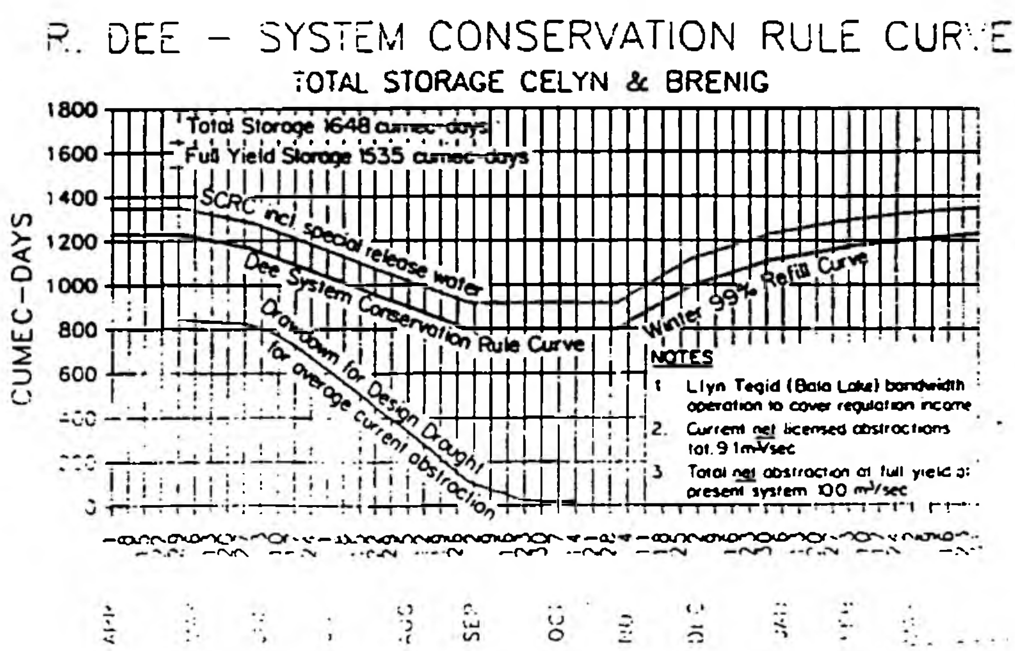


Figure 6. System conservation rule curve for the River Dee

There are also control rules (not reproduced here) for sharing releases between Celyn and Brenig, and for amalgamating Llyn Brenig and Alwen Reservoir compensation releases in a manner which both enhances the Alwen direct supply yield, and marginally improves Llyn Brenig refill. Despite the many man-years of research needed to evolve these rules for the Dee, their user-friendly graphical presentation enables the operators to determine many day-to-day actions simply by plotting levels or storages on the appropriate control rules graphs.

Most of the short-term forecasting systems (e.g. Lambert, 1973; Weston, 1979) used on the Dee, to quantify the management of releases down-river in drought or flood, were initially formulated during the Dee Research Programme (1966–76), then developed, refined, and put on computer as joint ventures between Welsh Water and specialist agencies (e.g. Lambert and Lowing, 1980). The resulting no-frills systems are practical, robust, and effective.

No matter how extensive their experience, it is essential that the managers and senior personnel responsible for river regulation are prepared to listen to constructive criticism, investigate new ideas, foster the spirit of research, and continue to learn. Whilst experienced managers are unlikely to over-react to a particular emergency, complacency can be avoided only if it is recognized that improvement is not only possible, but worth pursuing. There are few people who have mastered the art of effective communication between different disciplines, yet this is precisely what is required for river regulation management. On the Dee, and other North Wales rivers, no-one would claim to have achieved this yet, but we continue to try to improve our performance, and hope that such progress as has been achieved will encourage others to do likewise.

PRINCIPLES AND PRACTICES OF REGULATION ON THE DEE

The first 25 years

The basic objectives as stated in the Dee and Clwyd River Board Act 1951 were to set a prescribed flow of $2{\cdot}9\,m^3\,s^{-1}$ at a particular river gauging station on the Dee (Erbistock, later replaced by Manley Hall just upstream), which would allow continuous water supply abstractions downstream by a number of water undertakers. 'General Directions' would be drawn up to specify how the sluices at Llyn Tegid were to be operated to maintain this prescribed flow, having due regard to: (1) mitigating flooding; (2) securing the canal abstraction; and (3) safeguarding the fisheries.

This was a very low degree of regulation as natural flows at Erbistock only fell below this prescribed flow for two or three months in drought summers such as 1959. When Llyn Celyn was constructed the prescribed flow at Erbistock was raised to $7{\cdot}9\,m^3\,s^{-1}$, with the same objectives as in the 1951 Act. Regulation releases were required for several months in most summers between 1965 and 1973, but no severe drought was experienced. Demands rapidly rose to equal the yield of the system by 1974.

The Dee and Clwyd River Authority Act 1973 modified the objectives of regulation by adding that the General Directions should also have regard to 'any other purposes which, in the opinion of the Authority, are consistent with the purposes aforesaid'. This Act also created great flexibility for low flow regulation by allowing the General Directions to vary the prescribed flow, and the point at which it was measured. The only fixed Statutory Compensation Waters, those for Llyn Celyn, Llyn Brenig, and Alwen Resevoir are higher in April to September than in October to March. (Table II).

This flexibility was used in 1974, when an early spring drought was threatening severe supply restrictions later in the summer. The prescribed flow measurement point was moved to Eccleston Ferry, just upstream of the largest abstractions near Chester Weir, to take full advantage of natural runoff from the whole Dee catchment. Despite doubts that the difficult hydrometric conditions in the tidally affected Lower Dee would make it impossible to regulate the river accurately, unconventional yet reliable methods of gauging were employed (Weston, 1979) and the river has been successfully regulated to Eccleston Ferry ever since.

The pre-1974 prescribed flow was fixed by statute, and had to be sustained each day whether the licensed abstractions were taking place or not (a quite unjustifiable waste of precious storage on occasions). The flexibility of the 1973 Act allowed the maintained flow at Eccleston Ferry to be based on

Table II. Statutory compensation waters

	April–Sept		Oct–March		
	mgd	$m^3 s^{-1}$	mgd	$m^3 s^{-1}$	
Llyn Celyn	14·0	0·74	7·0	0·37	
Llyn Brenig and Alwen Res. together	5·5	0·29	3·0	0·16	Subject to 1 mgd, 0·05 $m^3 s^{-1}$ min from either

actual abstraction requirements (specified to the regulation control centre two days in advance) plus the design residual flow of 4·2 $m^3 s^{-1}$ over Chester Weir.

It is worth noting that, in the 1960s when several U.K. river regulation schemes were being implemented, there was serious concern as to the probable magnitude of regulation 'losses', i.e. the excess releases which would have to made to cover inaccuracies in forecasts of release requirements; figures of 10 to 15 per cent were commonly quoted. By specifying maintained flows which could vary in line with actual abstractions, and using forecasts of natural runoff based on simple recession curves with very accurate main-river flow measurement, regulation losses on the Dee can be held below 10 per cent in normal years: by changing the method of regulation under Drought General Directions they were reduced to 5 per cent in 1976 (Jackson and Bailey, 1978). In fact, excess releases are not really 'losses' to the river as they enhance the residual flow, and it is likely than in future on the Dee they may be considered as a variable component of the design residual flow.

In any river regulation system, situations will arise during severe droughts when storage conservation measures are unavoidable, often because it is not politically acceptable to assume that the drought will end as early in the autumn as previous droughts. Thus we have the concept of 'operational yield', as compared to the 'hydrological yield' which is retrospectively calculated from a particular drought sequence with a known end-date. On the Dee, which uses many individual control rules, it was decided to create a seasonal 'Conservation Rule Curve' (Figure 6) using aggregated storage of the two main reservoirs, to act as the trigger for optional initiation of conservation measures under 'Drought General Directions'.

Welsh Water suggested to the other abstractors represented on the DCC that an appropriate principle would be for a conservation action on the river to be accompanied by a conservation action by all four water supply undertakings, and it was agreed that under Stage 1 of the Drought General Directions, no river conservation action would be taken until all four undertakings had implemented domestic hosepipe bans under the 1945 Water Act. For the corresponding river conservation action, it was decided to temporarily change the method of regulation so as to release from the regulating reservoirs a daily amount equal to their minimum inflow plus the *net* abstraction requirements (after allowing for sewage effluent returns) upstream of Chester Weir. The effect of this would be that flows over Chester Weir under Stage 1 of DGD's would be approximately the same as if there was no abstraction scheme in operation, and regulation losses should be virtually eliminated as there is no accurate forecasting of river flows involved.

When this procedure was used during the 1976 drought, at a time of serious water shortage (Llyn Brenig had just started its initial 4-year filling) it was successful except that it did not provide adequate protection downstream of Chester Weir for the migrating salmon, and over 100 (out of an estimated run of 4000) died in the tideway. Determined to ensure no repetition of this in future, a detailed review of all available data on residual flows, fish movement, river quality, and temperature data at Chester Weir was undertaken by Welsh Water (Blezard and Lambert, 1979). It was concluded that:

1. During the annual grilse run (young salmon returning from the sea for the first time, usually in July) residual flows should exceed 5·5 $m^3 s^{-1}$.
2. Under DGD's stage 1, special releases should be made at times of high tides to safeguard migrating fish moving up the tideway.

The last decade

Since 1976, these revised procedures have proved satisfactory for over a decade, including the severe 1984 drought, when Stage 1 DGD's were implemented for a 7-week period from late July and there were no recorded fish mortalities attributable to regulation. It is now clearly recognized that there is no apparent benefit in seeking to maintain an *exact* fixed steady residual flow at all times.

Stage 2 of the DGD's envisages minor reduction of the releases under Stage 1, coupled with application by all four undertakings for Orders under Section 1·3(b) of the 1976 Drought Act for restriction of certain non-essential uses of water. Such applications were about to be made in early September 1984, for possible implementation in early October, when the drought broke.

Table III shows the current licensed and actual abstractions from the Dee upstream of Chester Weir. Table IV shows recorded average flows in the Lower Dee, on a monthly basis, for the period 1980–86, and the drought year of 1984. Because the largest abstractions are downstream of Eccleston Ferry, the whole river down to this point benefits from the regulation releases from upland storage to support these

Table III. Authorized and actual (1986) abstractions by designated abstractors

Abstractor	Authorized mgd	Authorized $m^3 s^{-1}$	1986 Actual mgd	1986 Actual $m^3 s^{-1}$	No. of Abstraction points
Welsh Water	5·2	0·27	1·96	0·10	1
North West Water	156·0	8·21	120·07	6·32	5
Wrexham Water Co.	8·0	0·42	5·78	0·30	2
Chester Water Co.	7·5	0·40	5·99	0·31	1
British Waterways Board	6·2	0·33	1·55	0·08	1
TOTAL	182·9	9·63	135·35	7·11	10

Note: Canal not fully operational in 1986 due to breach

Table IV. Regulated river flows. The following table shows the average daily flows ($m^3 s^{-1}$) on a calendar month basis, for the period 1980–86 inclusive; during this period the maintained flow at Eccleston Ferry has varied around 11·5 $m^3 s^{-1}$, except during late July to early September 1984, when Drought General Directions were in operation. The average monthly regulated flows for the drought year of 1984 are shown in brackets for comparison. During the period 17th April to 2nd September 1984, an average of 6·07 $m^3 s^{-1}$ was drawn from storage in Llyn Celyn and Llyn Brenig for low flow regulation of the Dee.

	Manley Hall	Eccleston Ferry	Chester Weir
January	55·6 (65·9)	69·0 (80·9)	63·1 (75·2)
February	38·0 (50·6)	49·7 (63·1)	43·6 (56·9)
March	39·5 (16·4)	48·3 (20·8)	42·4 (14·8)
April	23·9 (10·2)	31·3 (12·8)	25·4 (6·9)
May	18·0 (10·0)	22·8 (12·0)	16·8 (5·8)
June	15·4 (9·8)	18·7 (11·7)	12·7 (5·4)
July	11·0 (9·6)	13·2 (11·1)	7·0 (4·8)
August	17·1 (8·4)	19·7 (10·3)	13·9 (4·9)
September	20·2 (18·9)	23·3 (21·5)	17·4 (16·4)
October	39·4 (42·1)	44·3 (46·0)	38·4 (40·4)
November	51·0 (59·9)	60·1 (75·1)	54·1 (69·1)
December	56·4 (38·4)	69·0 (49·2)	63·1 (43·5)
Annual	32·1 (28·2)	39·1 (34·4)	33·2 (28.7)

Note: At the present informal maintained flow of 11·5 $m^3 s^{-1}$ at Eccleston Ferry, low flow regulation releases may be required from the reservoirs at any time between April and November.

abstractions. These regulated flows in the middle and lower reaches are several times greater than the natural minimum flow during July and August, and ensure that the fisheries are safeguarded even in such a severe drought. The flows over Chester Weir to the tideway show the effect of the abstractions, but are controlled in such a manner as to safeguard both the fisheries and the abstractions.

On regulated rivers in the U.K., effective management and limited conservation in the February to May period, before minimum flows occur, can often greatly reduce problems later in the summer of a drought year. This was never more evident than in 1984; for example, on the Dee, hydro-power releases from Llyn Celyn were stopped as early as February, to conserve storage, in accordance with the Control Rules (Figure 3). Other regulated rivers in North Wales, such as the Elwy and Dwyfor, did not have the flexibility of Dee regulation to conserve upland storage in Spring, and by July severe reductions in compensation water and residual flows had to be applied for. Drought Orders take time (four weeks minimum) to obtain, and will not be granted unless 'by reason of an exceptional shortage of rain, a serious deficiency of supplies exists or is threatened'; reaction rather than prevention. Welsh Water are seeking modifications to licences to operate their regulated rivers (other than the Dee) more flexibly in future to try to improve the management of existing resource systems.

DISCUSSION

The management of the River Dee encompasses a range of benefits in addition to the traditional ones of water supply and hydro-electric power production. In addition to coarse fishing in its lower reaches, the Dee yields some 2400 salmon annually, to nets and rods, and Llyn Brenig is a popular trout fishery. Welsh Water has fish traps on the Afon Tryweryn and Afon Alwen, its own hatchery near Corwen, and fish counters at Manley Hall and Chester Weir. The Area Fisheries Officer has immediate access to substantial special releases at his discretion, and arrangements have been made for extra-statutory enhanced compensation discharges from several regulating reservoirs in North Wales during the late Autumn, when migratory fish are moving up the tributaries, the reservoirs are refilling, and winter control rules show that there is no significant risk of prejudicing refill. Such discharges have a dual benefit by providing enhanced seasonal flood control storage at this time of year.

It is necessary to draw a distinction between safeguarding fisheries (an objective of Dee regulation) and attempting to create ideal conditions for catching migratory fish. The two objectives are not necessarily compatible, as evidenced by comparison of data for rod catches and movements through fish counters in 1984, when only 250 salmon were taken by rod and line, yet the fisheries were undoubtedly 'safeguarded'. However, as there is sometimes a correlation between river flow and fish catchability on certain reaches of river, an interrogable river level gauge has been provided at Manley Hall for use on the public telephone network, and this facility is intensively used by farmers and anglers.

The regulated Dee provides more than adequate dilution for the treated effluents upstream of water abstraction points; the effects of occasional pollution incidents arising from spillages or accidents can be mitigated also. Most are of no significance, but some can cause severe problems if they are not detected and enter public water supply systems. In January 1984, an unnotified discharge of phenolic compounds resulted in some 2 million people experiencing an unpleasant TCP taste on their tap water, drawn from the Dee, for several days. As all four Water Undertakings were affected, it was recognized that there were deficiencies in existing monitoring and emergency procedures, and comprehensive arrangements were introduced using pooled resources to set up an effective warning scheme, known as DEEPOL (Rushbrook and Beaumont, 1986). Since this was introduced in late 1984, all pollution emergencies likely to have adverse effect on public water supply have been effectively detected and monitored. Intakes are temporarily shut down, and special releases discharged from the regulating reservoirs to dilute the pollution and speed its passage down-river into the tideway. Such procedures obviously require reliable forecasting of time of travel at different river flows (Weston, 1987).

Riparian land owners are understandably concerned about the consequences of significant alterations to natural sequences of river flows, particularly during flood events. Will reduced peak flows and longer durations of medium discharge after the peak result in their land being waterlogged for longer? How can they judge when to take precautionary actions such as moving their stock, as the river rises? Will continuous controlled summer releases from a regulating reservoir deny them and their stock access across the river, or will sudden changes in flow cause a hazard? It is clearly the responsibility of the regulating Authority to investigate such questions thoroughly, and to initiate necessary actions where necessary such as provision of flood warnings, accommodation works, and warning notices. It is most useful to have a computer model readily available which can be used to show what *would* have happened in the absence of regulation control in a particular flood event. Figure 2a shows the effect of flood control at Llyn Tegid and Llyn Celyn on the outflow from Llyn Tegid during the October 1987 flood.

Hydropower generation at Llyn Celyn not only contributes to the national grid, and provides income for Welsh Water, but also creates an ideal situation for white water canoeing in the relatively short reach of river between Llyn Celyn and Llyn Tegid. Short period releases from Llyn Celyn can be 'caught' and 'balanced' in Llyn Tegid, so as not to cause significant fluctuations in river level downstream of Bala Sluices. Power generation income is not truly maximized at present, as water conservation and flood control have been given priority. Some consideration is also given to canoeing interests in the timing of releases. The loss of a relatively small amount of potential income is accepted as a reasonable price to pay for promoting and enhancing multipurpose use of the resources.

Llyn Brenig and its catchment area are particularly suited to outdoor and water-based recreation, and with the assistance of a local non-statutory advisory committee facilities have been provided for sailing, fishing, bird-watching, walking, and many other activities, including an archeological trial. The initial temporary visitor centre was so effective in attractin visitors (some 200000 throughout the year) that a permanent visitor centre has recently been constructed. The canoeing facilities on the Afon Tryweryn have also been developed with the assistance of a local advisory committee.

There is little doubt that, with the exception of the fishkill in the Dee Estuary during the 1976 drought, the objectives for regulation of the river, as set in the Dee and Clwyd River Authority Act 1973, have been met consistently. It is hoped that this brief exposition of Dee Regulation will provide a better appreciation of the many aspects which must be considered in the management of a regulated river. The key words are consultation, cooperation, compromise, and competence.

ABBREVIATIONS USED

DCC	Dee Consultative Committee
DCRA	Dee and Clwyd River Authority (integrated into Welsh Water Authority in 1974)
DGDs	Drought General Directions
MW	Megawatts
NRA	National Rivers Authority
RWA	Regional Water Authority
SSSI	Site of Special Scientific Interest
TCP	Tri-chloro phenol

WELSH WORDS

Afon	River
Llyn	Lake e.g. Bala Lake is also known as Llyn Tegid

APPENDIX 1: precis of the Dee and Clwyd River Authority Act 1973

(1) The Bala Lake works and the control sluices and appliances in connection therewith shall be operated by the Authority, and the discharges of water from Llyn Celyn and Llyn Brenig shall be regulated by the Authority, in accordance with General Directions to be issued from time to time by the Authority as normal general directions or drought general directions.

(2) Normal general directions shall–
  (a) prescribe the flow or flows of water in the River Dee to be maintained at Erbistock gauging station or elsewere, and the period or periods during which such flow or flows is or are to be maintained
  (b) ensure, as nearly as may be, maintenance of the said flow or flows at all times, except during a drought more severe than the design drought, whilst having due regard to the following purposes:
    (i) mitigating flooding
    (ii) securing a sufficient quantity of water for the canal abstractions near Llangollen
    (iii) safeguarding the fisheries
    (iv) any other purposes which, in the opinion of the Authority, are appropriate and consistent with the purposes aforesaid.

(3) Drought general directions shall describe the principles, and such detail as may be considered expedient and practical, in accordance with which the flow or flows prescribed by the normal gneral directions and the designated abstractions, shall be reduced in a drought more severe than the design drought.

(4) (a) The Dee Consultative Committee consitution shall be:

The Authority	3 representatives
Designated abstractors	1 representative each
British Waterways Board	1 representative

  (b) Meetings to be convened by the Authority, held at such intervals as the committee may decide, or at the instance of the Authority or upon request in writing to the Authority by any of the bodies represented on the committee.
  (c) The committee shall have the function of assisting the Authority in the formulation of general directions and the duty of commenting to the Authority upon any such directions as proposed or issued by the Authority.
  (d) The Authority shall, in preparing any such directions, consult and have regard to any views expressed by the committee.

(5) Drought general directions issued by the Authority shall be subject to the reasonable approval of each of the other bodies represented on the committee and, except as provided under (7) below, shall not come into operation until notice of approval has been given by each of such bodies. Drought general directions are deemed to be approved if not disapproved within two months of receipt.

(6) Drought general directions to be reconsidered and revised whenever reasonably so required by any of such bodies.

(7) Emergency drought general directions come into force immediately as from date of issue. They can be annulled by notification of disapproval by any body on the committee within three months, but are valid until disapproval notified.

(8) Differences or disputes to be referred to and determined by an arbitrator agreed between parties or appointed on application to the President of the Institution of Civil Engineers.

(9) Certain existing abstraction licences issued under Water Resources Act 1963 deemed to be subject to drought general directions.

(10) 'Design drought' is of a severity estimated to occur once in one hundred years;
'designated abstractor' is a statutory water undertaker or other person or body authorized by licence to abstract water from the Dee subject to a condition that the abstraction shall be subject to any drought general directions issued by the Authority.

ACKNOWLEDGEMENTS

Many have contributed to improving our knowledge and ability to manage this beautiful and interesting river. The Author accepts responsibility for the views expressed, and sincerely thanks all friends and colleagues too numerous to mention who have contributed so much to their formulation.

REFERENCES

Pearce, H. G., and O'Hara, K. 1984. 'The management and ecology of the Welsh Dee — an annotated bibliography', available from Water Research Centre.

Welsh Water Authority 1987. *General Directions for Regulation of the River Dee*

Lambert, A. O. 1985. *The Foundation for, and Work of, the Dee Consultative Committee*, one of 3 papers commissioned for a seminar in Kongsberg, Norway. Available from author.

Lambert, A.O. (in prep) 'Practical Operational Control Rules for Water Resources Systems using the Ten Component Method'

Lambert, A. O. 1979. 'Catchment Models based on ISO Functions', *J. Inst. Water Engineers*, 27(8).

Weston, A. E. 1979. 'The measurement of interactive freshwater and tidal flow in the River Dee', *J. Inst. Water Engineers and Scientists*, 33(1).

Lambert, A. O. and Lowing, M. J. 1980. 'Flow forecasting and control on the River Dee', in *Hydrological Forecasting*, Proc. of the Oxford Symp. April 1980. *IASH–AISH Publ.*, 129, 525–534.

Rushbrooke, J. N. and Beaumont, F. 1986. 'River Dee scheme and intake protection systems', *J. Inst Water Engineers and Scientists*, 40(2).

Jackson, H. E. and Bailey, R. A. 1978. 'Some practical aspects of river regulation in England and Wales', Paper presented to IWES River Engineering Section, available from Water Research Centre.

Blezard, N. and Lambert, A. O. 1979. Principal aspects of River Dee Abstractions and residual flows'. *Welsh Water Authority Report*, 78–012A.

Weston, A. E. 1978. 'Hydrology in the Incident Room', *Paper 25, National Hydrology Symposium*, British Hydrological Society Hull.

Tywi

SCHEDULE 3 - MANAGEMENT RULES

3.1 General Principles

Llyn Brianne Reservoir is used to regulate the Tywi to support an abstraction at Manorafon and further downstream an abstraction at Nantgaredig. Both abstractions are by the Undertaker and used conjunctively with other sources. There is provision for compensation water and freshet releases from Llyn Brianne for the river system, which is an important salmon and sea trout fishery for both commercial and angling interests.

A number of water quality problems have been identified in the river system. These are primarily the acidification of waters in the upper catchment, the low temperatures of water released from the bottom of the reservoir, and dissolved oxygen problems in the estuary at certain tidal states. Research into the effects of current operating practices is in progress and the results when available will be taken into consideration. In the meantime, the present practice of releasing water from Llyn Brianne at a uniform rate to support abstractions which, at times, are not uniform in rate, should continue.

The originally quoted yield of the Llyn Brianne scheme was 391 Ml/d. However, as part of the preparation of this Operating Agreement, the system yield has been re-evaluated on the basis of 'Operational Yield', which incorporates realistic assumptions as to the latest date when a drought would end. These calculations give an operational yield of 235 Ml/d (assuming no drought orders) or 253 Ml/d approx. assuming that a drought order was obtained which would not require the 136.4 Ml/d residual flow downstream of Nantgaredig to be maintained after 1st September in a drought year. These figures compare to the Undertaker's licensed abstraction of 263.7 Ml/d, and the current maximum actual abstraction of some 200 Ml/d.

Spare yield can be created in the system by the Undertaker reducing their abstraction at Manorafon and/or Nantgaredig below the licensed daily maximum when necessary, in order to allow the Authority the facility to allocate part of the operational yield to other potential abstractors. The Undertaker agree to make available to the Authority, if required, from the calculated operational yield of the regulation system, 15 Ml/d (or 25 Ml/d if no transfer link to the Cleddau system is constructed, or such other greater figure consequent upon upward revision of the operational yield if Drought Orders or other means of increasing the operational yield are permitted in future) of net abstraction capacity at any point or points on the river Tywi downstream of Llyn Brianne reservoir. The Undertaker also agree to operate their regulation facilities to enable such net additional licensed abstraction to be made by third parties.

These management rules provide a framework for ensuring that the Scheme operates in a way that maintains sufficient storage to meet demands with minimum need for Drought Orders. Proposals to improve the quality of the river Tywi can also be agreed and implemented within the framework. (See 3.7.3 below).

3.2 River Regulation Commitments

3.2.1 Abstractions:

The river regulation releases for Llyn Brianne are required:-

i) to support licensed abstractions from the Tywi by the Undertaker at Manorafon and Nantgaredig.

ii) to support additional unspecified future abstractions.

3.2.2 Compensation Water, Hands-Off Flow and Residual Flow:

a) Llyn Brianne: a uniform and continuous compensation flow of not less than 68.19 megalitres per day.

b) Nantgaredig Residual Flow: the rate of flow in the Tywi downstream of the intake shall not be allowed to fall below 136.38 megalitres per day.

c) Nantgaredig and Manorafon Hands-Off Flows: the abstractions at Nantgaredig and Manorafon shall be such that in total they will not exceed the quantity released from Llyn Brianne in the previous 24 hours when the natural flow in the catchment downstream of the reservoir is 681.9 Ml/d or less at Nantgaredig and/or 377.3 Ml/d or less at Manorafon.

Requirements for the magnitude of releases to meet abstractions when natural flows are approaching the above hands-off flows are specified in the relevant licences listed in part 1 of Appendix 2B to Schedule 2.

3.2.3 Regulation/Augmentation Releases:

Releases are made from Llyn Brianne to support the abstractions listed in 3.2.1 above subject to 3.2.2.(b) and 3.2.2.(c).

3.2.4 Generation of hydroelectricity:

None at present, but proposals may be brought forward in future.

3.2.5 Other Releases:

The Undertaker will, in any calendar year, release up to 9092 Ml in such amounts and for such durations as may be requested by the Authority subject to exceptional over-riding operational constraints. Such releases shall be categorised as "guaranteed freshet releases", and each time such a release is made the "residual guaranteed freshet release" for that calendar year shall be re-calculated. Such releases shall be allowed to pass over Capel Dewi weir substantially undiminished in quantity.

The Undertaker and the Authority may determine, through the Operating Manual and the Consultative Group (see 3.3 below) appropriate arrangements for opportunistic river management releases in addition to the "guaranteed freshet releases" when Llyn Brianne storage is within the "Potential Excess Zone" shown in the control rule, Figure 2.

It may from time to time be necessary to make releases from Llyn Brianne for reservoir safety or maintenance.

3.2.6 **Flood alleviation:**

There are no arrangements at present, but proposals may be brought forward in the future.

3.3 **Operating Manual**

The detailed local arrangements for operation of the Tywi Regulation Scheme will be specified in an Operating Manual.

The contents of the Operating Manual must be in accordance with the principles set out in this Agreement. The Operating Manual can be updated and revised as necessary without modification to the Operating Agreement, provided that such updates and revisions are agreed by both parties to this Agreement.

A small Consultative Group (the Tywi Consultative Group) will exist to assist in the updating and revision of the Operating Manual. Its function will be to agree procedures for the release of regulation water and freshets for river management, procedures for emergencies and Drought Order applications, to agree any updating and revisions to the Operating Agreement, and to undertake such formal or informal discussions relevant to the Tywi Regulation Scheme as may be necessary. The Consultative Group will consist of:-

2 representatives of the Undertaker and

2 representatives of the Authority.

The names of the representatives are specified in the Operating Manual together with such other information as may be appropriate.

The Consultative Group may, in undertaking their duties, liaise with specific local riparian interests, and Statutory Conservation Bodies, as and when the Consultative Group members agree such liaison is appropriate.

The first issue of this operating manual is to be prepared by the Consultative Group representatives prior to 1 March 1990, after which the Undertaker will be responsible for its production and distribution.

3.4 Exchange of Information

Provision is to be made in the Operating Manual for data exchange between the Authority and the Undertaker in relation to reservoir levels and storages, river levels and flows and abstractions at any site where such data is measured so far as it relates to the operation of the "Tywi Regulation Scheme".

3.5 Drought Management

The main principles of management of Llyn Brianne storage are summarised in Figure 2 which may be modified by mutual agreement of the Tywi Consultative Group.

3.6 Cost Apportionment

The Apportionment Ratio agreed is that the Authority shall contribute 100% of the costs as detailed in Schedule 4.

3.7 Other Relevant Matters

3.7.1 **The Undertaker shall consult the Authority before varying the management of any land if that variation involves any matter which is the subject of this Agreement.**

3.7.2 **Any information which the Authority may acquire relating to pollution incidents which could adversely affect the operation of the Undertaker's intakes or the quality of water abstracted is to be notified to the Undertaker without delay.**

3.7.3 **The Undertaker will meet the reasonable requirements of the Authority in improving the quality and temperature of water discharged from Llyn Brianne by varying the land management under their control and implementing such other measures as are deemed to be necessary by the Authority, provided that such measures do not conflict with any of the Undertaker's statutory obligations or levels of service. The cost of such works will be included in costs for the purposes of Schedule 4.**

SCHEDULE 4 - FINANCIAL PROVISIONS

4.1 Payments Dates

Payments will be made by the Authority to the Undertaker in respect of each relevant financial year commencing 1 April as follows:-

4.1.1 Four quarterly Provisional Payments on 1 July, 1 October, 1 January and 31 March in that year.

Environmental impacts of the Brianne River regulation Scheme

1.0 Impacts on Water Quality

Measured impacts:

1.1 Temperature: Water column thermally stratified during summer months. Maximum hypolimnetic temperature 8 degrees centigrade, up to 15 deg. lower than epilimnion. Release water is hypolimnetic causing 'Thermal Resetting' *NB. in the River Tywi. Impact observed for over 36Km (WWA 1988)

1.2 Sedimentation: Accumulation of iron and manganese rich precipitates in/on sediment immediately downstream of reservoir observed. Impact observed for 3Km to confluence with Doethie (WWA 1986). Sedimentation of other planktonic debris likely - enhanced due to hypolimnetic release.

1.3 Acidification: Upper Tywi catchment suffers from surface water acidification (low pH, low dissolved calcium and high aluminium concentrations). This has contributed to by afforestation associated with reservoir development. Historically therefore, reservoir was acidified and impacted main river Tywi downstream to Llandovery (11 Km). Reservoir displayed pH stratification (due to thermal stratification) and served to increase the severity and extent of acidification in the Tywi (primarily during regulation releases)(NRA 1990, WWA 1988).

* Thermal resetting
(A) reduction in mean summer temperature by up to 8 degrees Celsius.
(B) Delays in the onset of temperature rise in spring.
(C) Increased temperatures in spring.

** Liming of Llyn Brianne (since 1991) has ameliorated acidification impact in the Upper Tywi (NRA 1991). However, long term committment to liming has not been made therefore reacidification could occur.

2.0 Impacts on Aquatic Ecology

2.1. Benthic macroinvertebrate communities - The River Tywi for at least 1.5 Km downstream of the Llyn Brianne Dam has a severely depleted benthic macroinvertebrate community is quite severely depleted. The site would have been influenced by acidification up to Summer 1991 (See 1.3), but liming of the reservoir in Spring 1991 has not resulted in any major improvement at this site. Families of mayflies (heptagenidae), stoneflies (leuctridae, perlodidae), caddis-flies (sericostomatidae, goeridae) and beetles (Coleoptera) are consistently absent or present at low abundance. It is suspected that the observed impact may be due to the settling out of reservoir -derived deposits rich in manganese (see 1.2) and an unatural flow and thermal regime (see 1.3). Some 7.5 Km further downstream there is no measurable impact.

3.0 Impacts on Conservation/terrestrial ecology

3.1. The scheme flooded some 20,000 Ha of Welsh upland river valley including oak woodland which supported a characteristic flora and fauna. There was at least one pair of Red Kites nesting in the valley and the area had the potential to support further pairs of this species which is now spreading from its stronghold in mid Wales.

3.2 The flooding of the valley probably made farming uneconomic on the surrounding slopes which encouraged afforestation of the reservoir margins with conifer monoculture at the expense of moorland and its associated flora and fauna.

3.3 In 1991, 34 pairs of little ringed plovers (59% of the Welsh population) and 58 pairs of common sandpipers (20% of the welsh population) bred on gravel shoals on the lower river Tywi. If river flows in spring and early summer are significantly enhanced by releases from the Brianne dam, there is a danger that the nests may be destroyed. There is a potential threat also to sand martins and kingfishers which nest in river banks.

4.0 Impacts on Fisheries

4.1 Loss of spawning and juvenile habitat. Habitat previously used by migratory salmonids both within the impoundment and subsequently upstream and downstream of Llyn Brianne have been lost. Initially a trapping and trucking scheme was initiated but soon failed. Mitigation is now performed by means of a smolt stocking scheme.

4.2 Reduction in flows below dam. The reduction in the size and frequency of spates below the dam may have an impact on adult fish returning to the upper reaches by not attracting fish sufficiently high up the catchment to fully utilise the river directly below the dam. The reduced variation in flows has lead to the 'siltation' of gravels with material rich in manganese. This may reduce egg survival in the upper reaches though this impact has never been quantified.

4.3 Temperature effects on fisheries.
Reduction of mean summer temperatures by up to 8 degrees Celsius. (Section 1.1) and delays in the onset of temperature rise in spring, delaying both the onset of feeding and the emigration of parr/smolts.
Increased temperatures in winter may also shorten egg hatching times such that the fry hatch and swim up when suitable food items are not available.

4.4 Water quality within the dam. The acid waters study has demonstrated the upper Tywi catchment is seriously affected by acidification, although the effects of pH would be expected in the absence of the dam. The use of hypolymnetic releases may cause an increase in the severity and extent of the impact downstream, because of pH stratification. The impact has been addressed by the NRA over the past three years with an extensive liming project this is however expensive and will be reviewed with regard to funding in the future.

4.5 Organic debris. Reduction in both autocthonous and allochthonous detritus and debris, reducing contributions to food chains and habitat for juvenile salmonids.

4.6 Abstraction. Two major potable abstractions are supported by the scheme, one in the upper catchment at Manorafon, the main abstraction point being at Nantgaredig in the lower reaches a few kilometres above the head of tide. Nantgaredig abstraction is used extensively during the night.
Radio tracking studies on adult salmonids on the Tywi have shown that under 'low flows' fish show a preference to enter the river during the hours of darkness. Under low flows therefore the use of abstraction mainly during the hours of darkness may adversely effect the successful entry of fish to the river from the estuary.

The instantaneous operation of pumps on a night has been shown on some rivers to strand large numbers of juvenile salmonids on riffle areas. This may be a problem on the Tywi but has not been investigated.

4.7 Mitigation. A scheme involving the operation of several traps to capture ascending adults below the dam and upstream traps to capture descending kelts and smolts was initially set up as mitigation for the fisheries loss to the Tywi. Catches in both upstream and downstream catches quickly diminished and the scheme was eventually replaced by a smolt stocking scheme, which still continues.

There has been no evaluation as yet of the smolt stocking scheme which does not appear to be as successful as it might. The impact arises from once a mitigation scheme has been agreed, it is difficult to either increase the capital for the scheme or significantly alter it if it is proved to have little effect on the numbers of returning adult fish.

4.8 Public perception. Public perception of the NRA is also impacted by the dam. Any deterioration in the fishing whether this be real or perceived is blamed on the dam and the NRA. Criticism is often miss guided as anglers believe that releases from the dam occur frequently reducing the prospects for their sport.

There are some advantages.
1. flows are maintained to a greater extent during the summer increasing the overall wetted width and therefore probably area available to juveniles and the movement of returning adult fish.

2. There is a small capacity for fisheries releases. However current operational constraints prevent these being used to maximum effect and are perceived as having little overall benefit currently.

References

National Rivers Authority, 1990. Environmental impact of Polemical releases from Llyn Brianne. Internal Report No. PL/EAW/90/11 REAU 90/13.

National Rivers Authority, 1991. Preliminary results of the environmental impact of liming Llyn Brianne. Internal Report no. TM/EAW/91/14.

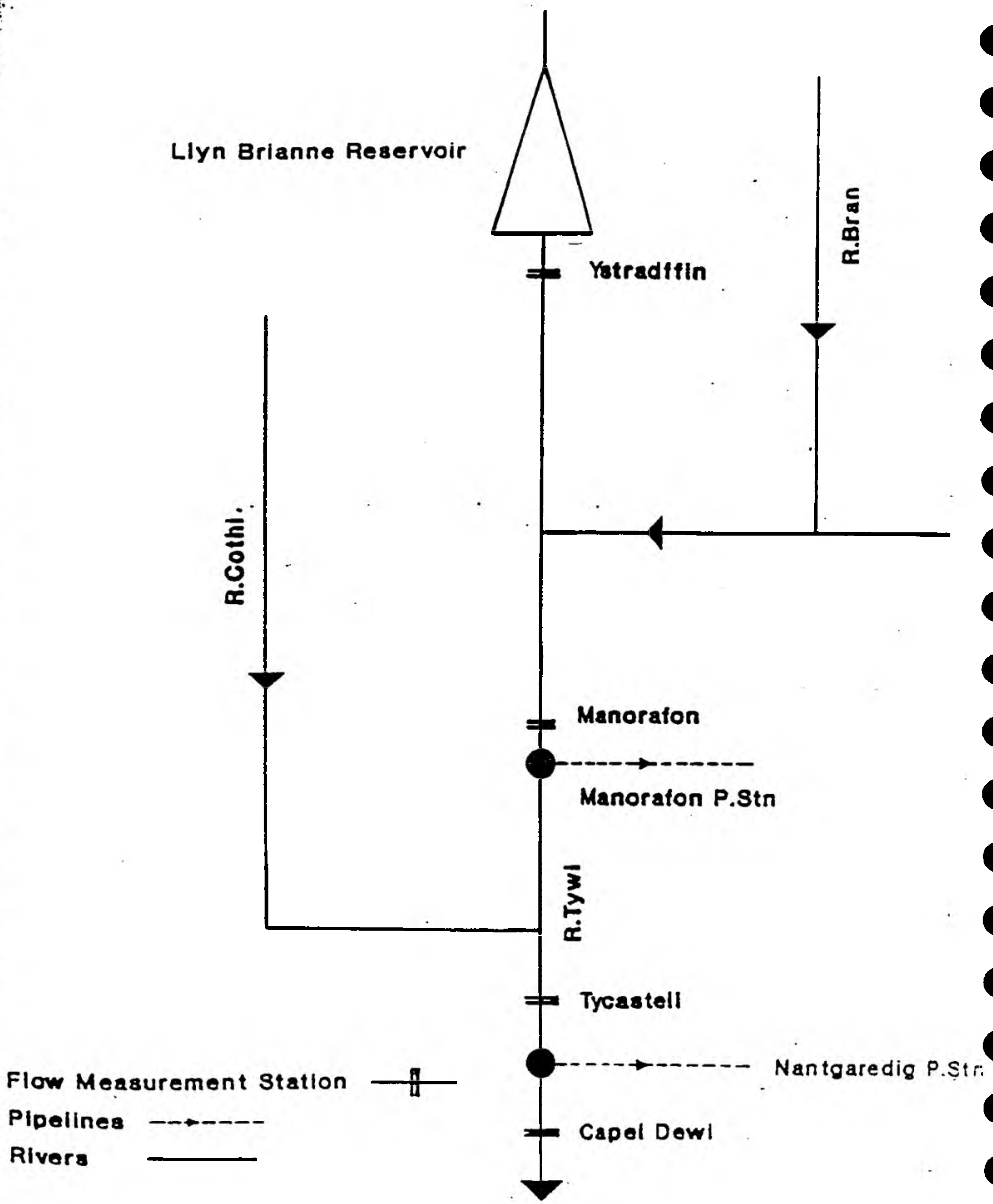
Tyler, S.J. (1992) Little Ringed Plovers in Wales in 1991. RSPB report for NRA.

Welsh Water Authority, 1986. A survey of Juvenile salmonid populations in the Tywi river system. Internal Report No. SW/86/4.

Welsh Water Authority, 1988. The water quality of Llyn Brianne and effects of regulation releases on the River Tywi. Technical Appendix to the Tywi Management Plan. Internal Report No. SW/88/27

National Rivers Authority, 1989. Migration of atlantic salmon (Salmo salar L.) in the river Tywi, South Wales. Paper presented to the Atlantic Salmon trust conferece on the fish movement in relation to freshwatre flow and quality.

Sketch of System



TYWI REGULATION SCHEME

Figure

WELSH

11

Environmental Assessment

-

Summary Sheets

Cleddau

SCHEDULE 1 - DESCRIPTION OF SCHEME

1.1 The Eastern Cleddau Regulation Scheme comprises the Llys-y-Fran reservoir and impounding dam together with the works and structures for the discharge and measurement of compensation and river regulation releases.

1.2 Llys-y-Fran Reservoir impounds the River Syfynwy (Syfni) and receives overflow and compensation water from Prescelly Reservoir which is a direct supply reservoir located higher in the catchment. The natural inflow to Prescelly can be augmented by pumping from the headwaters of the Eastern Cleddau at Pont Hywel. See Figure 1.

1.3 Compensation and river regulation releases are discharged into the Syfynwy which is a right bank tributary of the Eastern Cleddau.

1.4 Llys-y-Fran Reservoir has a gross capacity of 9090 megalitres which is used to regulate the Eastern Cleddau to support an abstraction at Canaston pumping station by Dwr Cymru cyf. The abstraction conditions are specified in Schedule 3.

1.5 The reservoirs and associated works included in this Agreement are detailed in Appendix 1A.

SCHEDULE 3 - MANAGEMENT RULES

3.1 <u>General Principles</u>

Llys-y-Fran Reservoir is used to regulate the Syfynwy tributary of the Eastern Cleddau to support the Dwr Cymru cyf abstraction from the Eastern Cleddau at Canaston. There is provision for compensation water and freshet releases for the river system which is a significant sea trout fishery.

The Scheme is the primary source for much of Pembrokeshire and is used conjunctively with other sources in Pembrokeshire, chiefly Prescelly reservoir, and the abstraction at Crowhill on the Western Cleddau. Llys-y-Fran reservoir is an important local amenity supporting recreational activities.

These management rules provide a framework for ensuring that the scheme operates in a way that maintains sufficient storage to meet demands with minimum need for Drought Orders. They also provide for the maintenance of adequate flows for other water users and general riverine ecology.

Spare yield can be created in the system by Dwr Cymru cyf reducing their abstraction at Canaston below the licenced daily maximum of 59 Ml/d when necessary, in order to allow the Authority the facility to allocate such spare yield to other potential abstractors. Dwr Cymru cyf agree to make available to the Authority, if required, from the calculated operational yield of the regulation system (57 Ml/d) up to [.......] Ml/d of net abstraction capacity at any point or points on the Eastern Cleddau or downstream of Prescelly reservoir. Dwr Cymru cyf also agree to operate their regulation facilities to enable such net additional licenced abstraction of up to ..... Ml/d to be made by third parties.

3.2 <u>River Regulation Commitments.</u>

3.2.1 **Abstractions.**

The river regulation releases from Llys-y-Fran into the Syfynwy are required:

i) to support a licenced abstraction from the Eastern Cleddau at Canaston by Dwr Cymru cyf.

ii) to compensate for any abstraction at Pont Hywel by Dwr Cymru cyf which would reduce the residual flow at Canaston weir below 6? Ml/d.

iii) to support additional unspecified future abstractions.

3.2.2. Compensation Water and Hands-Off Flow

a) Llys-y-Fran Compensation Flow: a uniform and continuous compensation flow of not less than 13.638 megalitres per day to be measured at an Authority approved gauging station within 250m. of the base of the dam.

b) Pont Hywel Residual Flow: a hands-off flow of 4.546 Ml/d.

c) Canaston Residual Flow: The abstraction at Canaston weir shall be such that a daily quantity equal to the natural flows from the unreservoired catchment area to Canaston weir (ie. excluding any contribution or compensation water from the catchement area from the Prescelly and Llys-y-Fran dams) shall be allowed to pass over Canaston Weir undiminished whenever such natural flows are 68.2 Ml/d or less.

3.2.3 Regulation/Augmentation Releases.

Releases are made from Llys-y-Fran to support the abstractions listed in 3.2.1 above and subject to 3.2.2 (c) above.

3.2.4 Generation of hydro electricity:

Generation limited to uniform and continuous discharge of compensation water at Llys-y-Fran.

3.2.5 Other Releases:

Dwr Cymru cyf will, in any calendar year, release up to 955 Ml at a rate not exceeding 68.2 Ml/d, at such times and for such durations as may be requested by the Authority, subject to exceptional over-riding operational constraints. Such releases shall be categorised as "guaranteed freshet releases", and each time such a release is made the "residual guaranteed freshet release" for that calendar year shall be re-calculated. Such releases shall be allowed to pass over Canaston Weir undiminished in quantity.

In addition, Dwr Cymru cyf and the Authority may determine appropriate arrangements for opportunistic river management releases in addition to the "guaranteed freshet releases" when the Llys-y-Fran reservoir storage is within the "Potential Excess Zone" (see Figure 2).

It may from time to time be necessary to make releases from Llys-y-Fran for reservoir safety or maintenance.

3.2.6 Flood Alleviation:

There are no explicit arrangements for the provision of storage for flood alleviation.

3.3 Operating Manual

The detailed local arrangements for operation of the Eastern Cleddau Regulation Scheme will be specified in an Operating Manual.

The contents of the Operating Manual must be in accordance with the principles set out in this Agreement. The Operating Manual can be updated and revised as necessary without modification to the Operating Agreement, provided that such updates and revisions are agreed by both parties to this Agreement.

A small Consultative Group (the Eastern Cleddau Consultative Group) shall exist to assist in the updating and revision of the Operating Manual. Its function will be to agree procedures for the release of regulation water and freshets for river management, procedures for emergencies and Drought Order applications, to agree any updating and revisions to the Operating Agreement, and to undertake such formal or informal discussions relevant to the Eastern Cleddau Regulation Scheme as may be necessary. The Consultative Group, which will consist of:-

2 representatives of Dwr Cymru cyf and

2 representatives of NRA

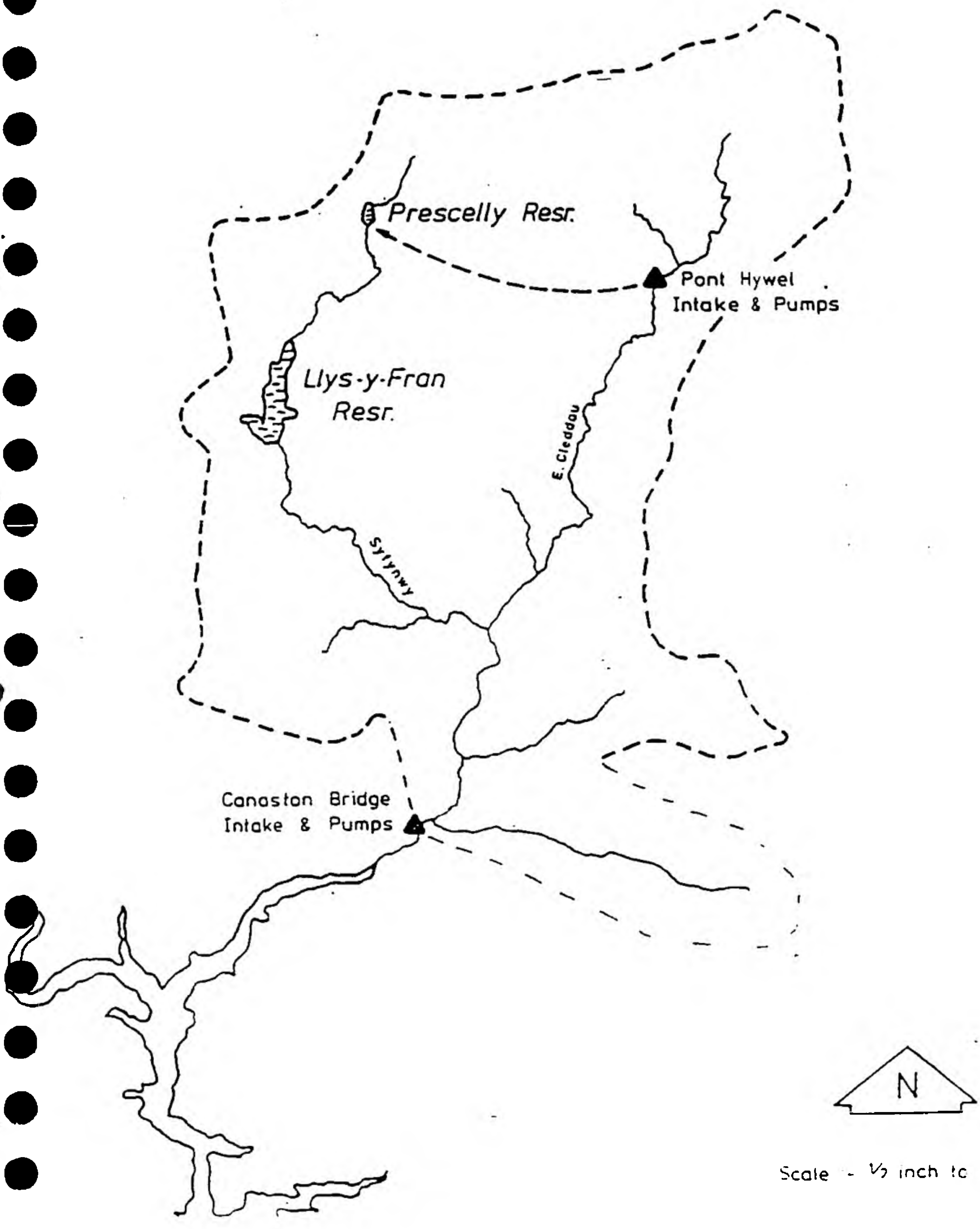
The names of the representatives are specified in the Operating Manual together with such other information as may be appropriate.

The Consultative Group may, in undertaking their duties, liaise with specific local riparian interests, Land and Leisure Ltd. and Statutory Conservation Bodies, as and when the Consultative Group members agree such liaison is appropriate.

The first issue of this operating manual is to be prepared by the Consultative Group representatives prior to 1 March 1990, after which Dwr Cymru cyf will be responsible for its production and distribution.

3.4 Exchange of Information

Provision is to be made in the Operating Manual for data exchange between the Authority and Dwr Cymru cyf in relation to reservoir levels and storages, river levels and flows and abstractions at the site where such data is measured so far as it relates to the operation of the "Eastern Cleddau Regulation Scheme".



Scale - ½ inch to 1 mi -

3.5 Drought Management

The main principles of management of Llys-y-Fran storage are shown in Figure 2 attached, based on plotting of Llys-y-Fran storage after deducting the "residual guaranteed freshet release". Figure 2 may be modified by agreement of the Eastern Cleddau Consultative Group.

3.6 Cost Apportionment

The Apportionment Ratio agreed is that the Authority shall contribute 100% of the costs as detailed in Schedule 4.

3.7 Other Relevant Matters

3.7.1 Dwr Cymru.cyf shall consult the Authority before varying the management of any land if that variation involves any matter which is the subject of this Agreement.

3.7.2 Any information which the Authority may acquire relating to pollution incidents which could adversely affect the operation of the Canaston intake or the quality of water abstracted is to be notified to Dwr Cymru cyf without delay.

Environmental Impacts of the Llys-y-Fran river Regulation Scheme

.0 Impacts on water Quality

1	Nutrients	Phosphate and nitrate inputs to the reservoir are high due to agricultural sources. Fish rearing in reservoir further increase nutrient inputs (WWA 1988). Consequently reservoir is meso/eutrophic, with regular blue/greem algal blooms developing. Reservoir development therefore, is likely to have increased nutrient loading to and productivity of the Syfynwy downstream.
1.2	Organics	Organic loading to Syfynwy is increased due to development of algal populations in reservoir and as a result of detritus from fish rearing practices. This may have implications for the dilution of effluents entering the Syfynwy and the long-term quality objectives for this river (WWA 1988).
1.3	Sedimentation	Deposition of algae and fish farm detritus immediately downstream of reservoir may decrease sediment oxygen concentrations.

2.0 Impacts on Aquatic Ecology

2.1 Benthic Macroinvertebrate fauna - For at the very least 200-300m downstream of Llys-y-Fran dam on the Afon Syfynwy the benthic macroinvertebrate fauna shows evidence of an impact. Certain mayfly families (heptagenidae and baetidae), stonefly families (perlodidae, leuctridae) and caddisfly families (sericostomatidae, goeridae) are either absent or present at unaturally low abundance. The effect may be due to siltation, growth of mats of Oscillatoria or due the unatural flow and thermal regimes (see 1.0)

2.2 Gudgeon are thought to have been introduced to the Syfynwy by anglers who use them as bait when fishing in Llys-y-Fran reservoir.

3.0 Impacts on Conservation/terrestrial Ecology

No major impacts have been identified. The reservoir, which holds a small wintering population of wildfowl, is seen as a valuable wetland habitat in an area which is deficient in such habitats.

4.0 Impacts on Fisheries

4.1 Loss of spawning area. There has been a loss of both spawning and juvenile salmonid habitat. This was however mitigated for and a smolt stocking [illegible] introduced.

2 Alteration of flow regime. The alteration of the flow regime may influence returning adults by dampening flood events, and therefore not inducing [illegible] high up the river to spawn such that the habitat is not fully utilised

3. A reduction in the amount of coarse organic debris from above the

impoundment contributing to habitat and food chains may reduce juvenile survival. Fine organic material has probably increased (see water quality section) increasing inputs to the food chain.

4. Increased sedimentation due to the organic enrichment of the impounded waters and the reduction in size and frequency of spates purging spawning gravels may impact on salmonid egg survival downstream.

5. Advantages.
Increased wetted width for juvenile habitat downstream during dry summers. Capability to release water to purge system in case of a pollution incident. Creation of a high quality put and take trout fishery. Managed by subsidiary of Welsh Water.

References

Welsh Water Authority, 1988. Llysyfran Reservoir: Fish Farming and its likely impacts on the reservoir and the downstream Afon Syfynwy. Draft Internal report.

NATIONAL WATER RESOURCES STRATEGY
ENVIRONMENTAL ASSESSMENT

National Rivers Authority, Southern Region.

Scheme - Alre Groundwater.

1. Schematic Map.

Not available. Sketch map to follow.

2. Objectives of Scheme

The Alre Groundwater Scheme is located on the tributary of the same name in the Upper Itchen catchment to the East of Alresford. The principal objective is the regulation of river flow by groundwater abstraction, as in the Candover Stream, to provide additional water to augment the Itchen, via the Alre during times of low flow.

As with the Candover Stream, secondary benefits relating to the stream ecology are met as a result of the augmentation.

3. Date of Implementation

The Alre Scheme was constructed during 1982/3, but was not tested until suitably dry conditions occurred in 1989. Since that time, there have been several periods of river augmentation from the R. Alre. However, the Scheme is not yet officially licensed for its operation.

4. Physical components of the Scheme

Four borehole sites are located around the village of Ropley, 5 kilometres to the East of Alresford. They are connected by pipeline to two discharge points at Bishops Sutton, 4 km. downstream on the R. Alre. The groundwater abstraction boreholes have a design yield of 56 Ml/d. with net yield approximately 45% of this figure. Flow in the Alre is measured at the permanent gauging station at Drove Lane, Alresford, whilst the Itchen flow is measured at Allbrook.

5. Frequency of Operation

Operation of the Scheme is initiated when the prescribed flow at Allbrook is breached. The frequency of use will be similar to that in the Candover catchment, i.e. an expected one year in seven.

6. Hydrology (Q95, DWF, ADF, MAF)

The hydrological impact will be similar to that of the Candover, except that the combined operation of both schemes will provide a total of 83 Ml/d at maximum output. The net yield will be considerably less. This will have a correspondingly greater effect upon the MRF at Allbrook at times of low flow.

7. Perceived/Measured Impacts.

A similar effect, under all headings, to that of the Candover Stream augmentation. Watercress production in the area requires similar protection, in the form of pumping plant supplied to the cress growers to compensate for the decrease in natural artesian flow.

8. Internal/Published Reports on Environmental Impacts

A Preliminary Report has been prepared by Southern Science but the exact details and official title are not available at the time of writing.

NATIONAL WATER RESOURCES STRATEGY
ENVIRONMENTAL ASSESSMENT

National Rivers Authority. Southern Region.

Scheme - Itchen Groundwater.

1. Schematic Map.

This is attached.

2. Objectives of Scheme

The Itchen Groundwater Scheme is located on the Candover Stream, a tributary in the Upper Itchen catchment between Basingstoke and Winchester. The principal objective is the regulation of river flow by groundwater abstraction and in particular the augmentation of the Itchen, via the Candover Stream, during times of low flow.

A number of secondary objectives are met as a result of increases in the minimum flow, notably a benefit to the general ecology and appearance of the watercourse downstream from the groundwater discharge locations.

3. Date of Implementation

Following a detailed Pilot Study between 1970 and 1975, the Scheme was commissioned after the 1976 Drought, during which a six-month period of continuous operation demonstrated the effectiveness of river augmentation under conditions of extremely low flow in the Itchen.

4. Physical Components of the Scheme

Six deep boreholes are drilled into the Chalk in three pairs which are located at Axford, Bradley and Preston Drove. The sites are approximately 3 to 4 kilometres upstream from the perennial head of the Candover Stream and have a total design yield of 27 Ml/d. The boreholes are connected by pipeline to two river discharge points at Northington village. Flow in the Candover Stream and the main river Itchen are measured by permanent gauging stations at Borough Bridge and Allbrook respectively.

5. Frequency of Operation

Operation of the Scheme is initiated when flow in the River Itchen at Allbrook decreases to below the Prescribed Flow, enabling the natural minimum to be artificially increased, and making more water available for abstraction at Gaters Mill on the outskirts of Southampton.

It follows that there is no regular regime of river augmentation: the Scheme is operated when required. It is calculated that augmentation is needed for an average of one year in seven.

6. Hydrology (Q95. DWF. ADF. MAF)

The net gain to the Itchen has been calculated at 90% during a six-month period of continuous augmentation during the summer of 1976. The Q95 of the Itchen at Allbrook is 254 Ml/d for the full period of record since 1958. The Prescribed Flow is set at varying levels through the year, with a minimum of 239 Ml/d in the summer months. Therefore the impact of 27 Ml/d by the operation of the Scheme is not great. An additional Scheme, based upon the R. Alre, has been developed to increase the groundwater available for low flow augmentation of the Itchen. The Alre Scheme is described as a separate Report.

7. Perceived/Measured Impacts (bullet points)

Geomorphology. There has been no measurable impact on siltation or erosion in the Candover Stream and no dredging has been required as a result of its operation.

Other Physical Impacts. No flooding or land drainage problems have arisen.

Water Quality. No adverse effects have been observed.

Navigation/Recreation/Amenity. The Candover Stream is too small for navigation. No adverse recreation/amenity effects are noted. In general, there will be a small benefit during low flow periods.

Aquatic Ecology. No adverse effects are noted.

Conservation/Terrestrial Ecology. As above.

Fisheries. As above.

Watercress Production. During the pilot studies there was a perceived effect upon the artesian borehole flows at a number of watercress farms in and around Alresford. The cress growers were provided with pumping equipment to restore the shortfall of natural artesian flow in the cressbeds.

8. Internal/Published Reports on Environmental Impacts

The Candover Pilot Scheme, Final Report (Southern Water Authority), June 1979.

MALMESBURY GROUNDWATER SCHEME

STREAM SUPPORT AND RIVER FLOW

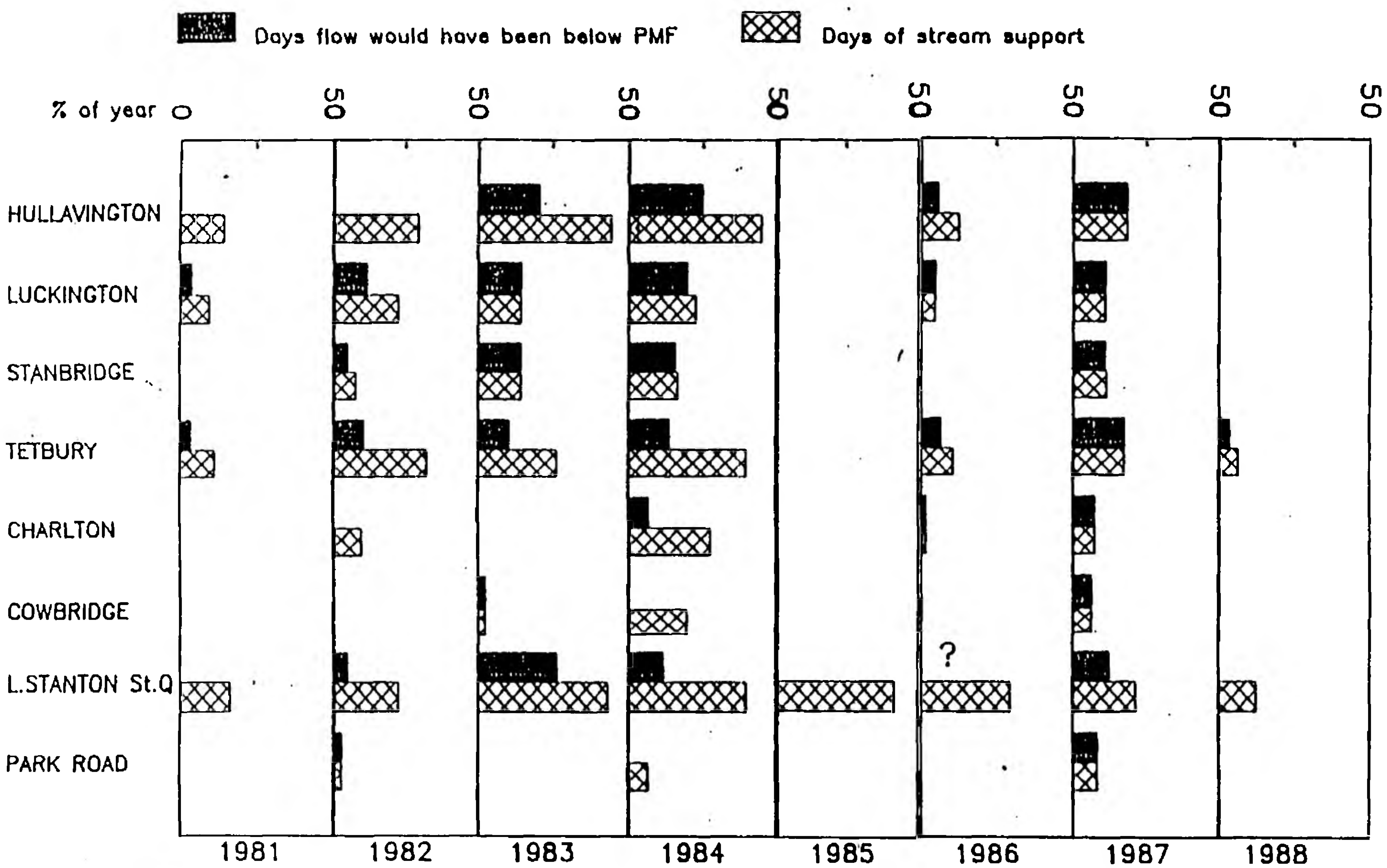
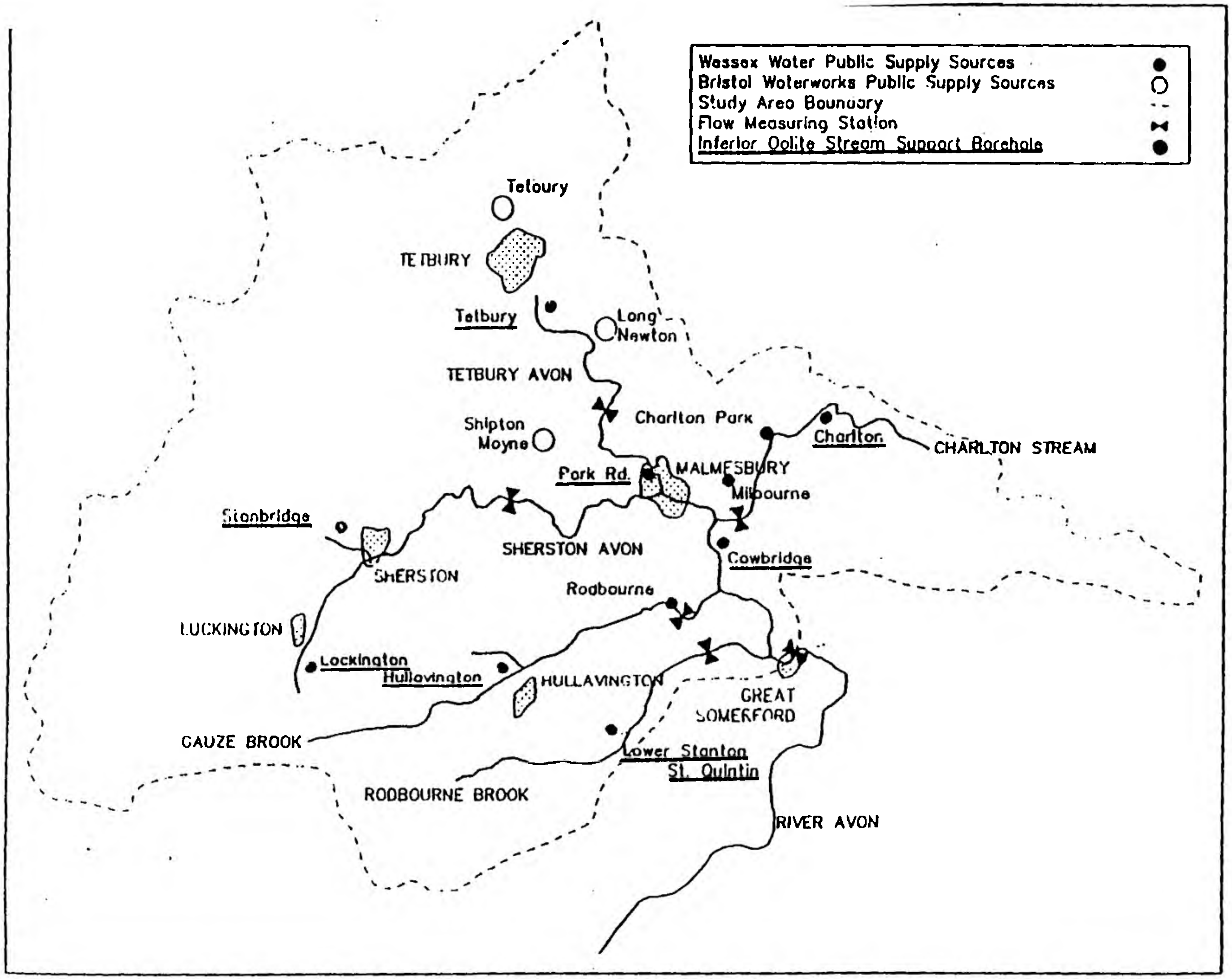


FIGURE 1.


Wessex Water Public Supply Sources
Bristol Waterworks Public Supply Sources
Study Area Boundary
Flow Measuring Station
Inferior Oolite Stream Support Borehole
Tetbury
TETBURY
Tetbury
Long Newton
TETBURY AVON
Charlton Park
Shipton Moyne
Charlton
CHARLTON STREAM
Park Rd.
MALMESBURY
Milbourne
Stanbridge
SHERSTON AVON
Cowbridge
SHERSTON
Rodbourne
LUCKINGTON
Luckington
Hullavington
HULLAVINGTON
GREAT SOMERFORD
GAUZE BROOK
Lower Stanton St. Quintin
RODBOURNE BROOK
RIVER AVON

NATIONAL WATER RESOURCES STRATEGY
ENVIRONMENTAL ASSESSMENT

National Rivers Authority, Southern Region.

Scheme - Ardingly Reservoir / R. Ouse

1. Schematic Map.

This is attached.

2. Objectives of Scheme

The Ardingly Scheme provides for the natural storage, treatment and movement of water using piped mains where required. Its operation is governed by a legal agreement between the NRA and South East Water plc (formerly Mid Sussex Water Company). Ardingly Reservoir provides release water into the River Ouse, via the Shell Brook at times of low flow, whilst during high flows, the reservoir may be filled from the Ouse when required to maximise storage.

3. Date of Implementation

1978 approximately.

4. Physical Components of the Scheme

4.1 Ardingly Reservoir. Situated 2 kilometres West of Ardingly village, the reservoir has a maximum capacity of 5200 megalitres.

4.2 River Ouse intakes at Ardingly and Barcombe. At these two locations water is drawn directly from the river in readiness for supply.

4.3 Treatment Works. These are located on the Shell Brook, Ardingly and at Barcombe on the Ouse about 25 km. downstream from the reservoir. Water is treated for quality and pumped into supply.

R RESOURCES STRATEGY
ENTAL ASSESSMENT

;hority, Southern Region.

chen Groundwater.

ieme is located on the Candover
Upper Itchen catchment between
. The principal objective is the
y groundwater abstraction and in
n of the Itchen, via the
mes of low flow.

ctives are met as a result of
low, notably a benefit to the
ance of the watercourse
water discharge locations.

Study between 1970 and 1975,
after the 1976 Drought, during
continuous operation
ess of river augmentation under
flow in the Itchen.

ne Scheme

led into the Chalk in three
xford, Bradley and Preston
mately 3 to 4 kilometres
head of the Candover Stream
d of 27 Ml/d. The boreholes
two river discharge points at
the Candover Stream and the
ed by permanent gauging
nd Allbrook respectively.

nitiated when flow in the
reases to below the Prescribed
nimum to be artificially
ater available for abstraction
ts of Southampton.

tion is a
ithin certain

ion of 4.5 Ml/d.

ring conditions
spills over the

reservoir are made
in the Shell
ow in the R. Ouse
low the Shell

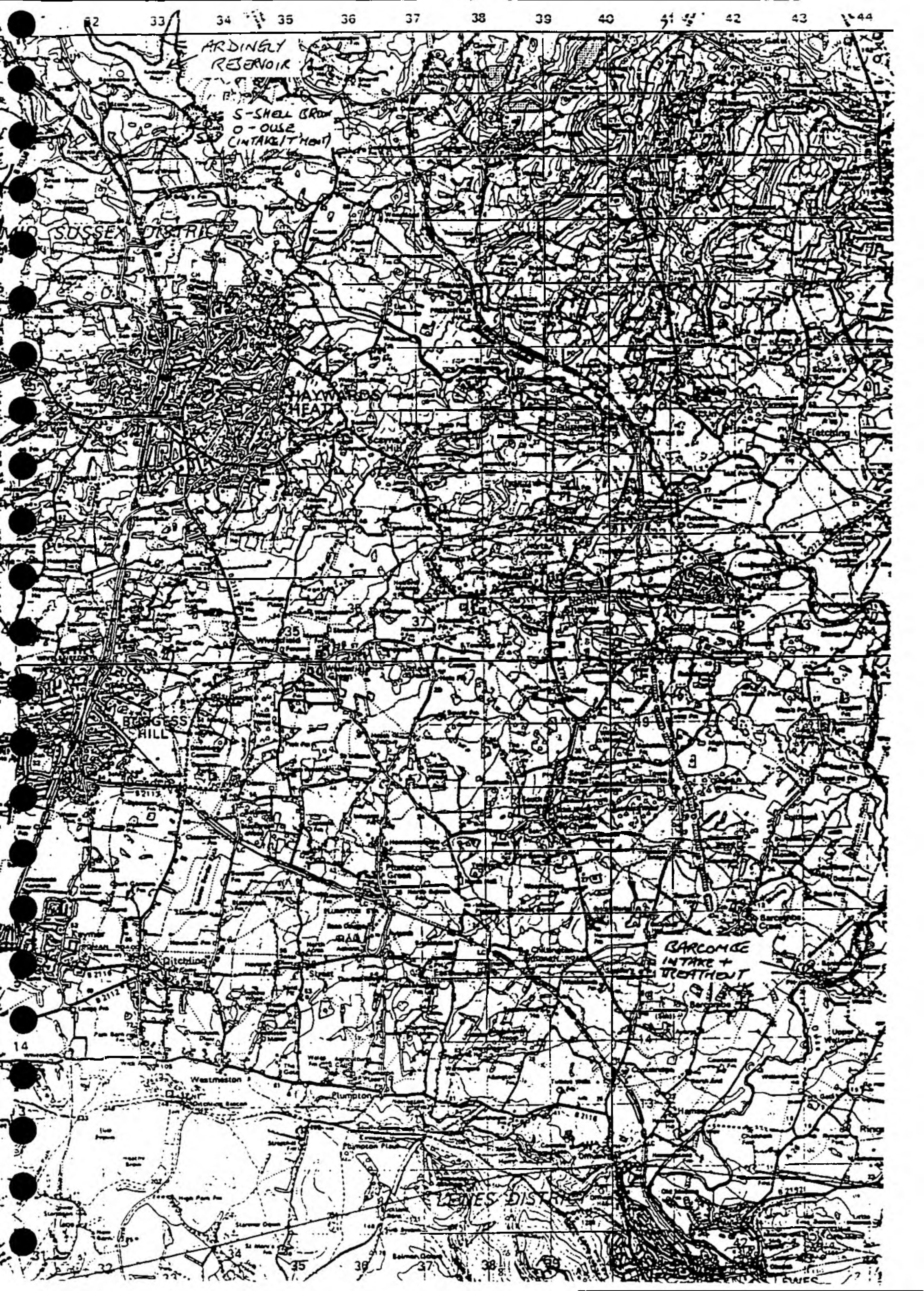
ern the operation
reviewed from time
ith East Water
, to ensure optimum
.

oints)

hanges in the flow

onmental Impacts

thern Water



ARDINGLY RESERVOIR
O - OUSE
(INTAKE/T'MENT)
HAYWARDS HEATH
BURGESS HILL
Ditchling
Plumpton
Westmeston
BARCOMBE INTAKE + TREATMENT
Fletching

NATIONAL WATER RESOURCES STRATEGY
ENVIRONMENTAL ASSESSMENT

National Rivers Authority, Southern Region.

Scheme - River Medway Scheme

1. Schematic Map.

This is attached.

2. Objectives of Scheme

The Scheme was designed to augment water supplies to North West Kent with the resource supplying both Southern Water plc and the Mid Kent Water Company. There are a number of secondary benefits, namely:

2.1 Natural ecological benefits at times of low flow in the R. Bewl, Teise and Medway.

2.2 Bewl Reservoir. This is a main recreation location with picnic areas, car parking and an Information Centre for visitors. The reservoir caters for sailing, rowing and sub-aqua diving, whilst there is a Nature Reserve and trout fishery.

3. Date of Implementation

The Medway Scheme was commissioned by the former Medway Water Board in 1968, and is now the responsibility of Southern Water plc.

4. Physical Components of the Scheme

4.1. Bewl Reservoir. Situated near the village of Lamberhurst on the Kent-Sussex border, Bewl is the largest storage reservoir in Southern Region with a maximum capacity of 31,300 megalitres.

4.2. Associated pipework to supply water to Mid Kent directly from storage at Bewl, and to refill the reservoir from Smallbridge Pumping Station on the R. Teise.

4.2. Smallbridge Pumping Station. Flow is gauged at Smallbridge and water is pumped back into Bewl Reservoir under river flow conditions specified in the licence.

4.3. Teston Gauging Station. The controlling station on the River Medway. Operation of the Medway Scheme is based upon the flow at Teston and Smallbridge.

4.4 Springfield Intake (Southern Water Services plc.).

A major Public Water Supply abstraction from the Medway immediately downstream from Maidstone.

5. Frequency of Operation

The refilling of Bewl Reservoir from the River Teise and the release of water to support riverflow in the catchment are both governed by the Springfield/Medway Scheme licence. Operation of the Scheme is permitted under Drought Order legislation, once the flow at Teston decreases below a particular threshold. This allows reservoir releases to be made, and/or when flow conditions permit the reverse process i.e. the refilling of Bewl Reservoir from the Teise. It follows that these operations impart a seasonal pattern upon the Scheme, e.g. with reservoir releases most likely during dry summer periods and refilling during the winter.

6. Hydrology (Q95, DWF, ADF, MAF)

Management of the resource creates an artificial impact upon the catchment, especially in the R. Bewl and R. Teise which are quite small watercourses.

The Q95 at Teston is 125 Ml/d and at times of low flow, the Medway will be increased by releases from Bewl. The maximum possible augmentation is 65 Ml/d.

7. Perceived/Measured Impacts

Little or no impact upon the main River Medway due to the relatively small percentage increase in flow during augmentation. There is a greater effect upon the Bewl and the Teise. The impacts created by the reservoir are considerable, and these are described in Section 2.2

Geomorphology. No measurable impact.

Other physical impacts. No flooding or land drainage problems have arisen.

Water Quality. Probably an improvement in water quality in the Bewl and Teise at low flows during reservoir releases.

Navigation/Recreation/Amenity. A small amenity benefit on the Bewl and Teise.

Conservation/Terrestrial Ecology. Little or none.

Fisheries. Little or none.

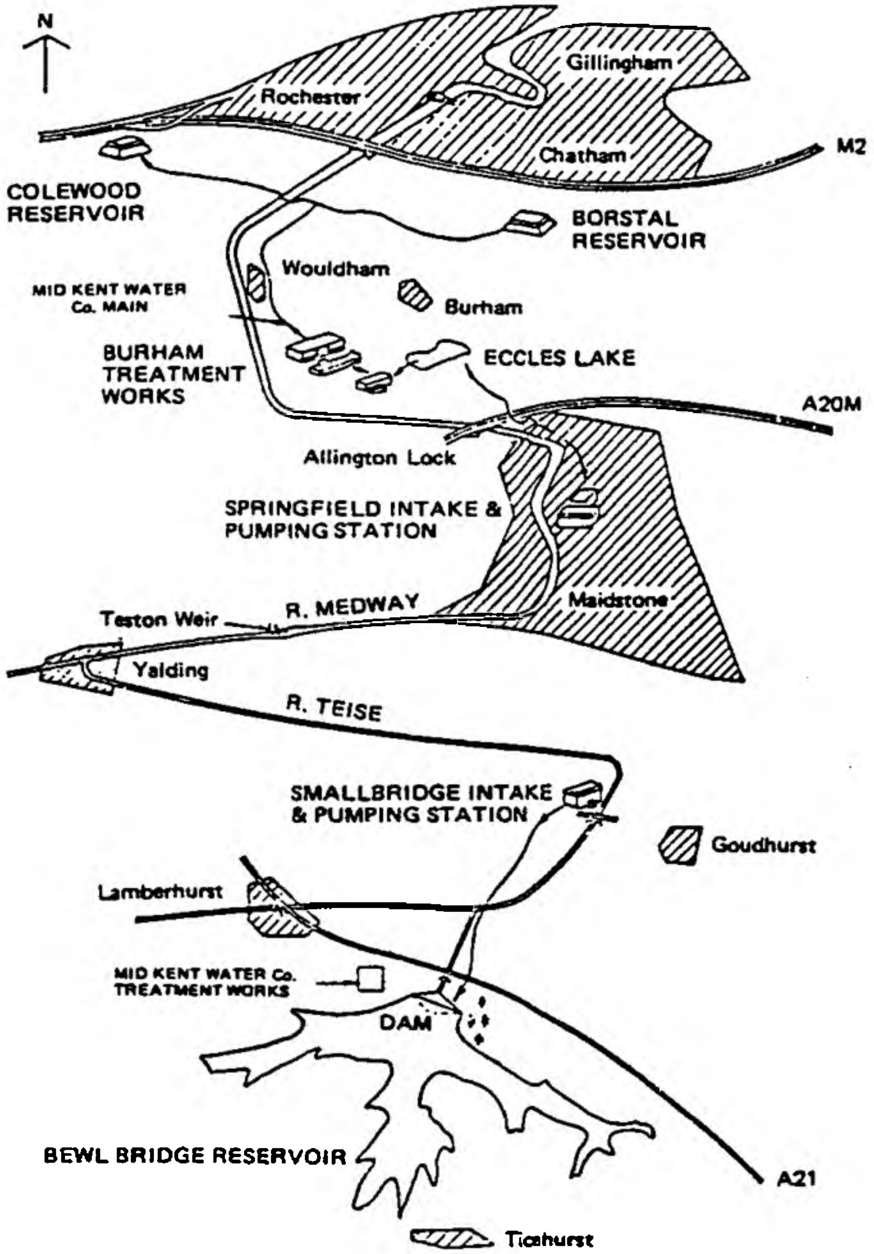
8. Internal/Published Reports on Environmental Impacts

River Medway Catchment Management Plan. Phase 1.

(National Rivers Authority), 1991

SOUTHERN WATER

RIVER MEDWAY SCHEME



SCHEMATIC DIAGRAM

NATIONAL WATER RESOURCES STRATEGY - ENVIRONMENTAL ASSESSMENT

SCHEME SUMMARY SHEET - WIMBLEBALL/EXE SCHEME

Objectives of the scheme

Wimbleball is used all year for public water supply as a direct supply out of catchment to Maundown WTW (Wessex Water) which is also supplied from Clatworthy reservoir. In addition nearly every summer augmentation releases are made down the river Exe to support public water supply abstractions for Allers and Pynes WTWs (South West Water).

WTW - Water Treatment Works

Date of Implementation

The first full year of impoundment of Wimbleball was 1978.

Physical components of the Scheme

A pipeline from Wimbleball transfers raw water to Maundown WTW. Controlled releases from the reservoir to the river Haddeo are for:

- Compensation water - 9.1 Mld
- Augmentation releases to the Exe - up to around 40 Mld*
- fisheries releases - at least 900 Ml* over 3 years
- Scour valve testing

* Pumped Storage Scheme will allow a significant increase in the supported abstractions so augmentation releases will increase significantly. The fisheries water bank will be increased to 900 Ml each year.

In addition uncontrolled seepage through the left bank abutment and toe drain flows can exceed compensation water quantities when the reservoir is full.

In March this year a pumped storage scheme was approved in principle. The abstraction point will be at Exebridge just above the Barle/Exe confluence and subject to a prescribed flow. Water may only be pumped during November to March.

South West Water also hold abstraction Licences of Right for around 27 Mld from the river Exe at any time.

The augmentation releases for South West Water are made when the river flow at Thorverton gauging station is less than 273 Mld. In addition a 10% additional release is made for 'losses'. This practice has not been substantiated to the NRA's satisfaction. Over releases during augmentation and for compensation water requirements are also prevalent and are under investigation at the moment.

Frequency of operation

Few summers are so wet that no augmentation releases are required. Typical periods of augmentation are June to August though exceptionally it could extend to mid-November.

The direct supply element may peak during six months of the year to 45 Mld but the maximum average yearly take is 32 Mld.

The pattern of direct supply abstraction significantly influences the available storage for river augmentation. At present no discernable strategy for conjunctive use between the two water companies and the river is apparent.

Hydrology: with/without

Considerable hydrological work has recently been carried out as part of the determination of the pumped storage scheme. Flows on the Exe have been naturalised and a generated runoff sequence back to 1856 for Thorverton is available.

Impacts: perceived/measured

<u>perceived</u>

- Lower Summer flows in the Exe
- Lower Spring and Autumn flows
- Reduced migratory fish population blamed on changed flows
- Passage of fish hindered at weirs blamed on changed flows

<u>measured</u>

- Enhanced summer flows to lowest abstraction point (Pynes)
- Some reduction of flows above the prescribed flow from unsupported abstraction for public water supply
- Over releases of augmentation water/compensation water offset reduction in flow below Pynes
- Short deprived stretch immediately below Pynes before river Culm tributary

Water Quality

Current water quality only available as there was no formal requirement for pre/post scheme appraisals for this reservoir. No specific post impact studies have been undertaken.

Predictions suggested that it could become eutrophic within about 10 years, increased nutrient loading from more intensive upland farming is evident.

Nutrient levels are increasing in reservoir but no problem as yet. Soon to be implemented pumped storage scheme may advance this.

Fisheries

The Reservoir situated at the head of the Haddeo system (River Exe) directly reduced the available spawning and nursery territory upstream of the dam site. This is mitigated for by stocking salmon smolts each year.

Salmon no longer run as far as the dam site on the Haddeo and salmon production in this part of the system has declined noticeably. This is probably due to the fact that in the late Autumn when fish are reaching the headwater spawning grounds, Wimbleball Reservoir will not be overspilling and only compensation flows are available in the Haddeo system.

During low flows releases from the Reservoir augment river flows and are considered beneficial to fisheries interests.

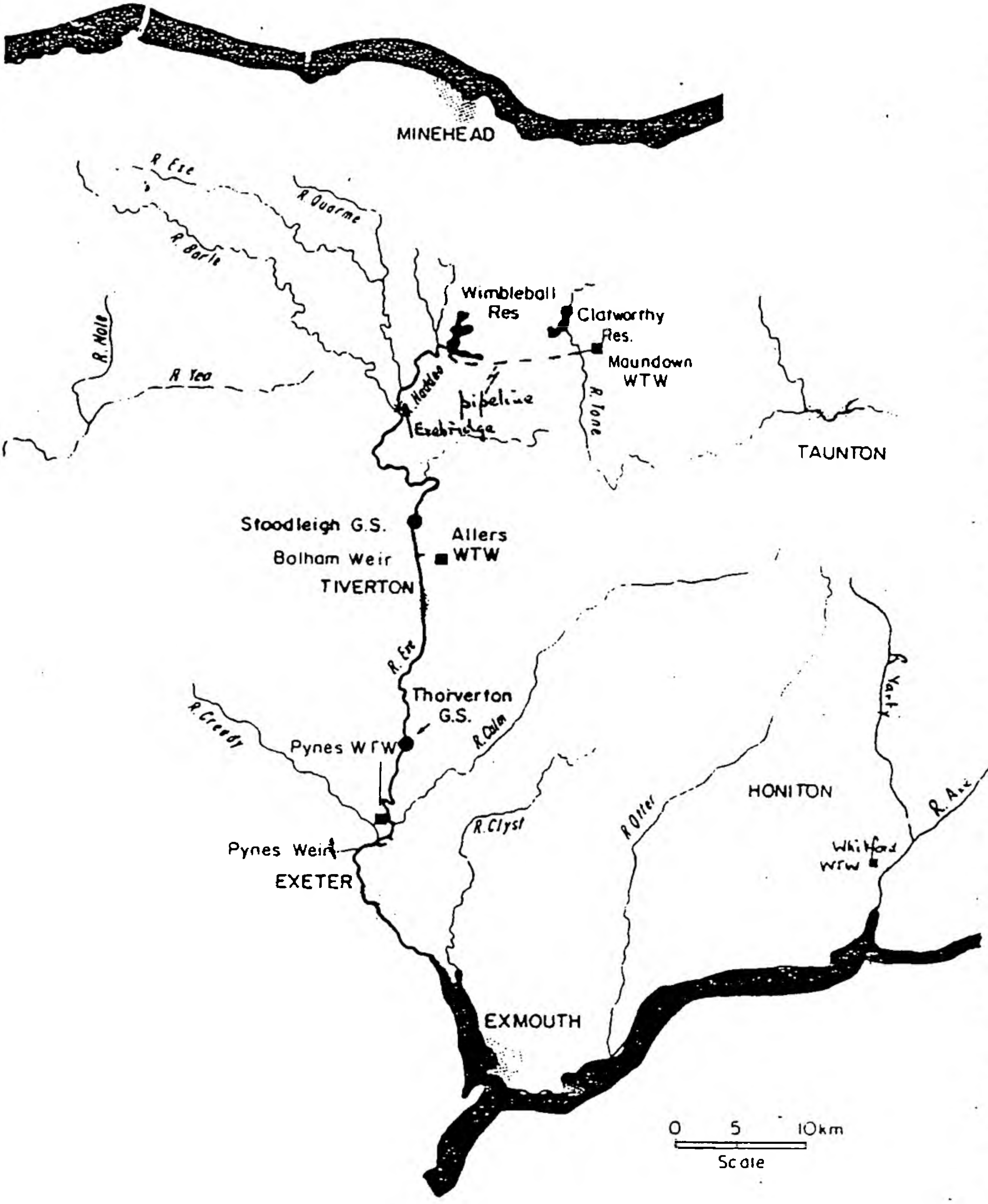
Recreation

Recreational activity in the River Exe itself is not affected to any extent by the Reservoir. Within the Reservoir, recreational facilities have been developed for informal pursuits and water sports. The Reservoir is an important trout fishery and is used extensively for sailing, canoeing and rowing purposes.

Conservation

Variations in flow in the Haddeo have been shown to have some detrimental effect on dippers and vegetation.

In association with the Wimbleball scheme the recently licensed pumped storage scheme operating from Exebridge during the Winter months may have some effect on fisheries/recreation/conservation interests but these should be minimised by the operating rules.

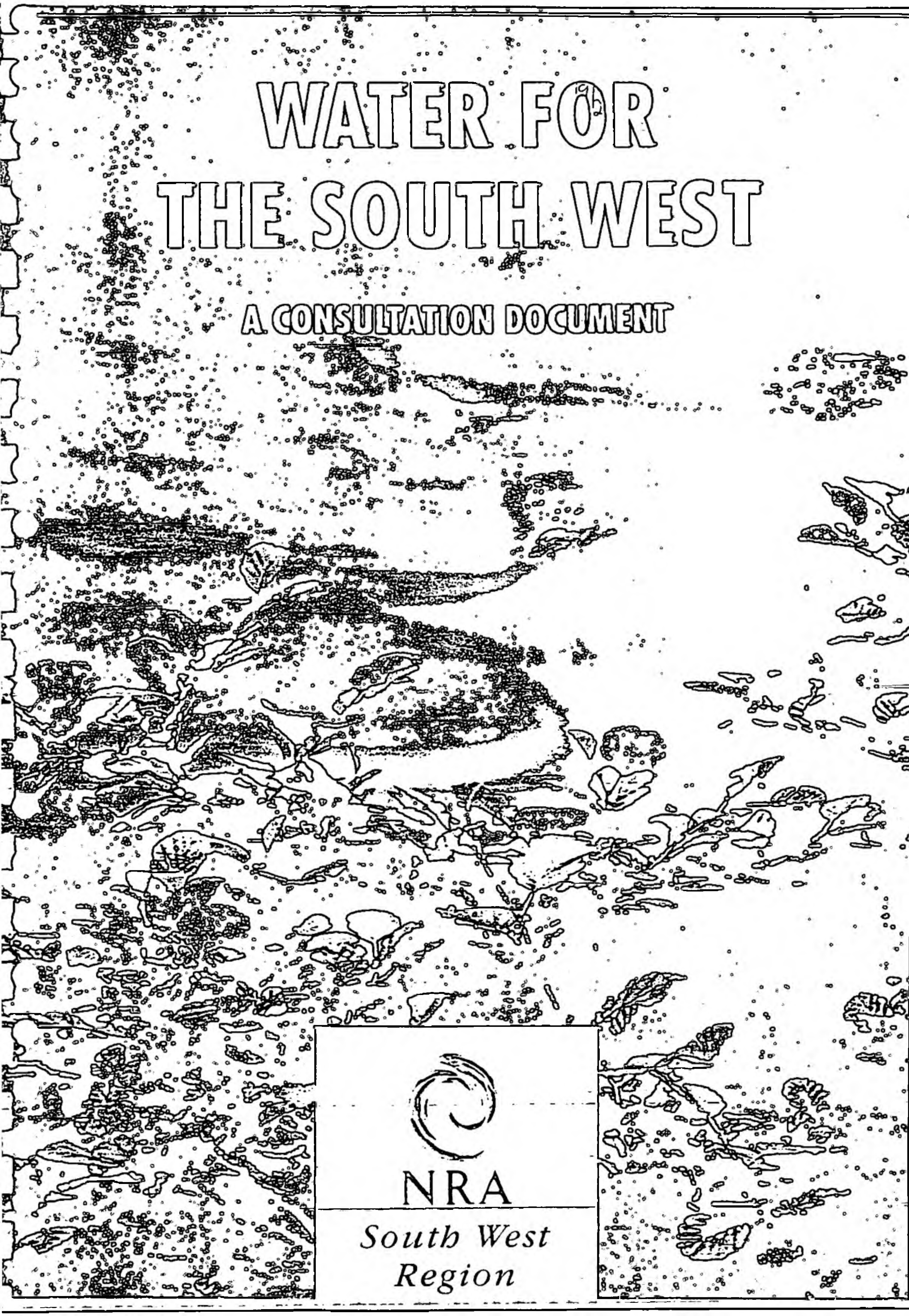


LOCATION PLAN

Figure 1

WATER FOR THE SOUTH WEST

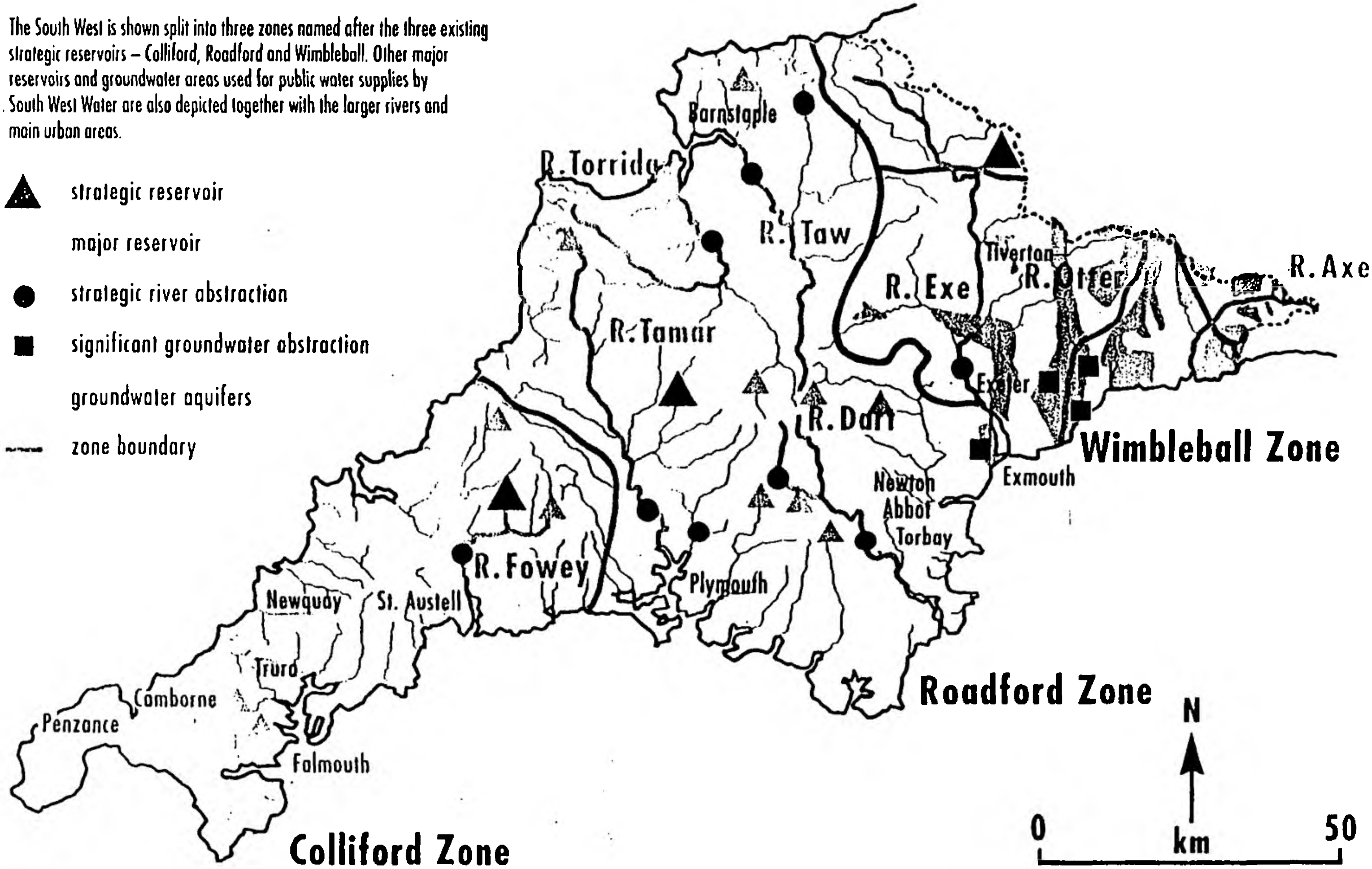
A CONSULTATION DOCUMENT



NRA

South West Region

The South West is shown split into three zones named after the three existing strategic reservoirs – Colliford, Roadford and Wimbleball. Other major reservoirs and groundwater areas used for public water supplies by South West Water are also depicted together with the larger rivers and main urban areas.



INTRODUCTION

The National Rivers Authority (NRA) has a duty to conserve, redistribute and augment water resources and to secure their proper use. In carrying out this role the NRA must also meet its general duties for environmental conservation and have particular regard to the statutory obligations of water supply companies.

Proper use of water resources involves not only meeting the reasonable and legitimate water uses of abstractors and dischargers, but also protecting river flows for aquatic life, conserving and enhancing wildlife, landscape and archaeological features associated with waters under NRA control.

A national discussion document published by the NRA in March 1992 looked at the future of water resources in England and Wales as a whole. It concluded that major inter-regional transfers would not be needed to meet anticipated shortfalls in water resources in the South West, given that over the next 30 years the region can be self-sufficient in water resources.

The South West Region of the NRA is now preparing its regional water resources development strategy for the next 30 years. The strategy will provide a framework within which the NRA will consider future applications for abstraction licences, and a basis for abstractors, including South West Water, to plan future water resource schemes to meet forecast increased water use. **Consultation with the public is important and will help to finalise the plan.**

The South West Region of the NRA therefore commissioned an independent consultant, Sir William Halcrow and Partners of Swindon, to produce a report as an initial stage of preparing a Regional Water Resources Strategy.

The consultant's report was presented to our Regional Rivers Advisory Committee in April 1992. The NRA is now seeking public comment on the report's conclusions and recommendations.

This consultation document:

- presents the NRA's interpretation of the key conclusions and recommendations from the consultant's report
- presents information on the balance between estimates of the present reliable availability of water and increased water use in the South West
- identifies possible water resources options for meeting future water use
- invites comment on identified options and related issues.

The NRA expects to complete and publish its first Water Resources Development Strategy for the South West during 1993.

The period of consultation will run until the 31st of October 1992.

FACTS AND DEFINITIONS

Water resources is a general term describing the reliable quantity of water available for all users from rivers, reservoirs and underground water. It includes the water available for abstraction and the water that needs to be left in the aquatic environment.

Abstraction is the removal of water from these sources. Most abstractions of water require an *abstraction licence* from the NRA. These permit abstraction up to a given maximum daily and annual quantity. Many licences have conditions attached which restrict the quantity abstracted or even require it to cease when it is necessary to protect river flow, the river environment and other abstractors' rights.

A *strategic reservoir* is a source of water which can be used to supply a large part of South West Water's overall water supply area. A *strategic zone* is part of the region which can be fed from an existing strategic reservoir.

Pumped storage schemes involve pumping water from a river into a reservoir during the winter to help boost the quantity of water in storage for the next summer.

When describing water supply systems or river flows the volume of water used is commonly expressed in metric units as megalitres per day, abbreviated to Ml/d. There are a million litres in one megalitre.

(One million gallons per day is the common imperial unit and is equal to 4.546 Ml/d.)

Most people use about 140 litres (30 gallons) each day at home. One megalitre therefore represents the household use of about 7000 people.

Table 1 below shows, for comparison, recorded flows in Ml/d at the most downstream point of measurement, for some of the larger rivers in the region. These rivers are shown on the map on the inside cover.

Table 1 Average, Minimum and Maximum Flows for Larger Rivers in the Region

River	Flow (Ml/d)		
	Minimum	Average	Maximum
Exe	37	1361	24993
Axe	39	428	12736
Otter	38	267	5522
Dart	51	947	23151
Tamar	50	1927	41668
Fowey	23	409	8422
Taw	18	1554	28908
Torridge	10	1321	28839
Hayle	12	84	623

KEY CONCLUSIONS AND RECOMMENDATIONS

Water Use

- Domestic water use is likely to rise by about 1% a year over the next 30 years in the South West.
- Whilst it has not yet been possible to forecast private abstractors' water use with confidence, the only apparent area of growth is spray irrigation, particularly in West Cornwall and in the East Devon valleys of the Exe, Clyst and Otter.
- In the medium term additional links between and within the three strategic zones – Colliford, Roadford and Wimbleball – will help make best use of the existing water resources for public water supply purposes.

Developments

- There is considerable scope for further water resource development within the region. Although new development is likely to be cheaper than seeking to reduce growth in water use, by for example metering all consumers, every opportunity should be taken to ensure that water is used wisely.
- Pumped storage of Wimbleball, Roadford and Colliford reservoirs will be needed to meet anticipated shortfalls in water resources. These schemes are attractive because they make best use of the existing reservoirs and help delay the need for wholly new developments.
- Some phased redevelopment of the Otter Valley boreholes within existing licensed water resources appears possible before the development of the first reservoir pumped storage scheme.
- The future needs of neighbouring Wessex Water could be met entirely from developments other than Wimbleball pumped storage but the relative benefits of this option need to be further investigated.

Timing

- There is already a temporary shortage of water resources in East Devon and the Wimbleball Strategic zone as a whole is also likely to be the first to experience an overall shortfall in water resources.
- The next major water resources development scheme should be Wimbleball pumped storage. The implications for South West Water of developing Wimbleball in the near future, as an alternative to promoting an Axe pumped storage scheme, require further investigation.
- Although the requirement for a major new reservoir scheme is at least 20 years away, long term planning of the "next generation" of major new storage schemes to meet anticipated needs in 20 years time should begin now.

FORECAST WATER USE AND EXISTING WATER RESOURCES

Public Water Supplies

Table 2 shows forecast use of water by South West Water's customers at ten year intervals between 1991 and 2021 for each of the three strategic zones: Colliford, Roadford and Wimbleball. The forecasts represent average daily use over a year and assume leakage control planned by South West Water is implemented successfully. Short term and seasonal peaks in water use also need to be taken into account in any detailed planning, especially in an area like the South West with clear seasonal influxes of tourists.

The average increase in the use for water of about 1% a year results mainly from expected population growth and each person using more water.

Estimates of existing water resources available to South West Water to meet these requirements are shown in Table 3. Colliford, Roadford and Wimbleball reservoirs and their associated river abstractions supply most of the available resources in each zone. These reservoirs operate by releasing water into river systems for subsequent abstraction downstream. Water from Roadford for example is abstracted from the River Tamar at Gunnislake before treatment and distribution to Plymouth and South Devon. Water can also be pumped directly from Roadford to water treatment works for use in North Devon. Similarly Wessex Water pump water from Wimbleball to Maundown Water Treatment Works for use in Somerset.

On the basis of the average daily forecasts of water use and the existing estimates of water resources a regional shortfall of water resources is predicted between 2011 and 2021. However, shortfalls may occur earlier if short term and seasonal peaks in water use are also considered and a 5% planning margin is introduced to help provide a buffer against the uncertainties of the forecasting process. Clearly from the comparison of average forecast water use and existing water resources the Wimbleball zone will require further water resources before 2011 and within the zone some development is required now.

Table 2 Forecast use of water to the year 2021 (Ml/d)

Year	Colliford zone	Roadford zone	Wimbleball zone	Total
1991	149	252	96	497
2001	154	260	100	514
2011	184	298	114	596
2021	216	338	130	684

Table 3 Existing water resources available to South West Water (Ml/d)

Year	Colliford zone	Roadford zone	Wimbleball zone	Total
1991	204	332	110	646

ENVIRONMENTAL CONSIDERATIONS

Acceptable flows for aquatic life

Rivers in the South West support resident and in most cases migratory fish. Studies of migratory fish movement indicate how sensitive they are to changes in flow and water quality. These changes also affect the distribution of the resident fish population along the river. Surveys of the flora and fauna indicate the 'health' of the watercourse. Any new water resources developments need to take account, at the detailed planning stage, of the need to protect and foster fisheries, recreation and conservation and other potential impacts on the environment.

Low flow problems

The NRA has recognised the possible adverse impact of low flows in rivers caused by particular abstractions. An initial desk study in the South West highlighted a number of sites throughout the region where some adverse impact was perceived. These sites include private abstractions as well as abstractions for public water supplies. Some of these abstractions were taking place when the Water Resources legislation was introduced in 1963 when many existing abstractors had to be granted licences allowing them to continue to abstract up to their previous maximum rates regardless of the consequences for the environment. A similar situation arose following the introduction of the 1989 Water Act when various abstractions which had previously been exempt from licensing under the 1963 legislation, such as fish farms, were also brought within the licensing requirement. Investigative work is now under way on the sites with the greatest perceived problems.

Private Water Supplies

Private sector abstractions which take water directly from rivers, lakes/reservoirs or groundwater rather than from South West Water's supply systems are mainly for agricultural and industrial uses. Table 4 shows quantities authorised for abstraction in the South West for purposes where a significant proportion of water is not returned to local sources.

Spray irrigation is usually considered separately from other private sector uses. Although it only represents a small proportion by volume of all water licensed for abstraction in the region it is the only use identified as showing a marked potential for growth (see Table 4). It mainly occurs in the far eastern and western parts of the region. The demand tends to be greatest during droughts when water resources are at their lowest.

The preliminary forecast of up to a 4% annual growth rate in spray irrigation in the region is based on a review of historical trends in total licensed quantities and assumes full use of authorised quantities. A similar review of agricultural and industrial uses indicated no significant growth.

An overall decline in agricultural and industrial use in England and Wales generally may partly be attributed to the introduction of more efficient processes and partly due to a shift in the national economy away from production towards service industries.

However, these trends are by no means certain to continue - climatic change could have significant effects; clearly further work is required to define existing and future demands within the private sectors. Research into these areas of water use is progressing both regionally and nationally.

Fish farming, amenity use and hydropower generation have been excluded from Table 4 as generally most of the abstracted water is returned to the river reasonably close to the point of abstraction and is therefore available for re-use downstream, subject to there being no deterioration in quality. Such abstractions can however lead to local shortages of water resources in bypassed river reaches.

Table 4 Water Use by private abstractors (Ml/d)

Year	Colliford zone			Roadford zone			Wimbleball zone			Total
	SI	Ag	IP	SI	Ag	IP	SI	Ag	IP	
1991	24	6	108	14	11	63	48	15	31	320
2001	35	6	108	21	11	63	71	15	31	361
2011	52	6	108	30	11	63	105	15	31	421
2021	76	6	108	45	11	63	155	15	31	510

SI - Spray Irrigation Ag - Agricuture IP - Industrial Processing

Solutions may involve revocation or modification of some licences. This is likely to lead to the reallocation of available water resources. Preliminary estimates suggest that up to 36 Ml/d of the existing reliable water resources available to South West Water may be required to alleviate a number of perceived low flow problems associated with public water supply abstractions. If these water resources were used to alleviate proven low flow problems the implementation of major developments for public supply would have to be brought forward.

Water Quality

Generally the quality of river water in the region is perfectly acceptable for potable supply, subject to appropriate treatment. Some rivers though, notably those in West Cornwall, are of poor quality due to historic mining activities.

Groundwater quality in the region is also generally good although the quantity of water available from a number of public and private groundwater sources has been reduced as a result of increasing nitrate levels. The NRA has recently developed a draft policy framework for groundwater quality protection which is now being implemented.

Climatic change

If climatic change is going to adversely affect the overall availability of water resources and demands on the resource, it is likely that this will take place gradually. This will therefore allow sufficient time for necessary changes to be made to our strategy.

OPTIONS FOR MEETING FURTHER INCREASED WATER USE

The NRA has a duty to ensure proper use of water resources and expects a high degree of attention to be paid to the 'wise use' of water. Attention to these aspects could delay the need to develop new resources.

Public Water Supplies

In the context of public water supplies proper use includes reviewing the present use of water after it is abstracted and looking at potential benefits from the more flexible use of existing sources. This includes zonal transfers from areas of surplus to areas of deficit. Effective leakage control is considered essential.

Table 5 Recommended Water Resource Developments

Water Resource Development	Ml/d	Year
1. Redevelopment of Otter boreholes	7	1999
2. Wimbleball pumped storage	37	2001
3. 20 Ml/d zonal transfer from Wimbleball-supported abstractions to Roadford	-	2006
4. Colliford pumped storage	50	2006
5. Roadford pumped storage	50	2011
6. River Creedy abstraction	7	2012
7. Axe pumped storage reservoir	22	2017
8. Zonal transfers of up to 5 Ml/d from Wimbleball to Roadford and from Roadford to Colliford	-	2019

The NRA encourages the 'wise use of water'. It supports managing the demand for water and may, for example, require such activities as selective domestic metering in areas where water resources are stressed, as well as requiring formal resource management strategies to be prepared for drought situations.

The NRA will not grant licences for new public water supply abstractions without first being completely satisfied that water companies are paying proper attention to effective demand management and doing all they can to reduce leakage to economic levels.

In the South West river flows in the summer are often so low that direct abstraction is not tenable. The capture of winter flow for storage represents the only reasonable way to ensure demands for water can be met at all times. Thankfully, the recent completion of South West Water's 'three reservoir' strategy has boosted reservoir resources in this region. The amount of water available can be greatly enhanced by pumping surplus winter river flows into existing reservoirs. Pumped storage schemes therefore represent the most attractive development option for meeting future increased public water use requirements.

The main water resource developments recommended by the consultants are listed in Table 5 along with the quantity of water each would yield and a best estimate of when it would be required. These estimates assume that the planned reductions in the volume of leakage from South West Water's mains system are achieved.

Other development options such as desalination of sea water or pumping treated effluent into aquifers on a large scale are currently considered uneconomic in this region.

Private Water Supplies

The principles of securing the proper use of existing sources and encouraging the wise use of water applies equally to private abstractors.

It is anticipated that private abstractors will seek licences from the NRA to meet any increased water requirements. The NRA may not grant licences for abstractions where a significant proportion of the abstracted water is not returned to the local source, without the development of storage to sustain abstraction during low flows.

SUMMARY

The NRA consultants suggest that additional storage will be needed to ensure the future availability of water and that this can be done without causing damage to the region's water environment. Pumped storage schemes to top up existing reservoirs in the winter appear the most appropriate development option to secure future public water supplies. This would make best use of existing reservoirs, provide further resources and significantly delay the need for new major reservoir schemes, while having potentially the lowest environmental impact.

If you have any views on the consultant's recommendations, please use the questions on the loose leaf insert to help form your reply and return any comments to:

The Water Resources Planner
National Rivers Authority - South West Region
Manley House
Kestrel Way
Exeter
Devon
EX2 7LQ

A full copy of the technical background report 'Water Resources Development Strategy' may be obtained by post or in person from the main Exeter office.

A cover charge of £8 is payable plus £2.12 postage and packing. Cheques should be made payable to 'National Rivers Authority South West Region' and sent to the address above.

Copies of the 'Water Resources Development Strategy' report and further copies of this document can be requested via an answerphone service. This service also provides an opportunity to leave short comments.

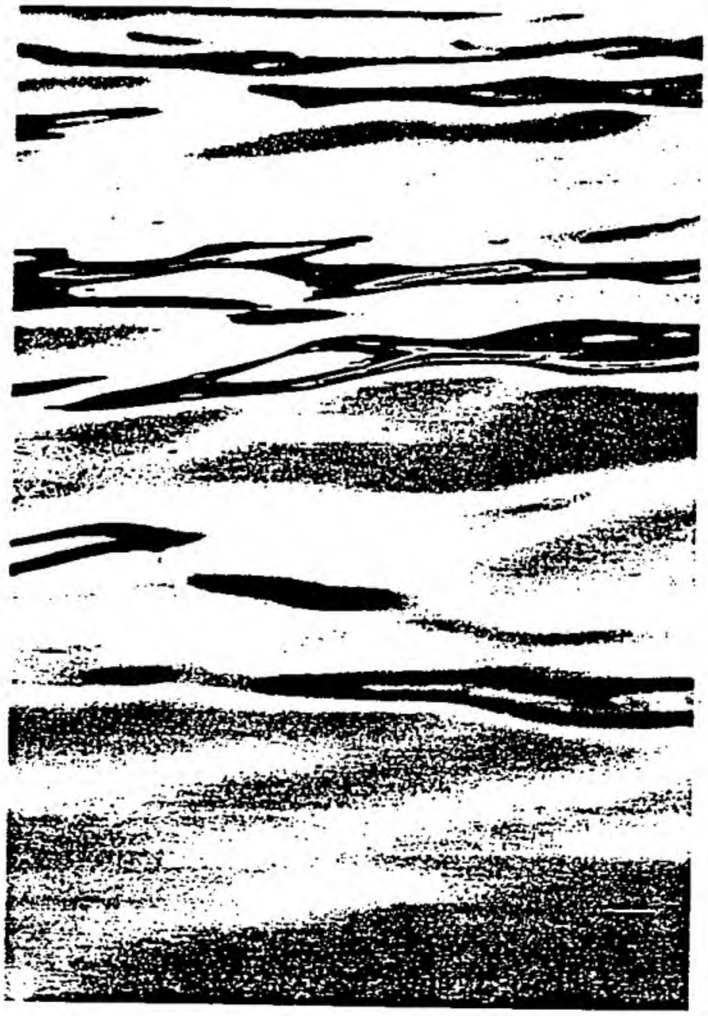
The telephone number of the answerphone service is ...

0392 442027

It will operate 24 hours a day including weekends until the end of the consultation period.

Your call will be dealt with on the next working day.

THE CONSULTATION PERIOD ENDS ON THE 31st OCTOBER 1992.



This brochure was produced by the Public Relations and Water Resources Sections. National Rivers Authority, Manley House, Kestrel Way, Exeter, EX2 7LQ. Tel: Exeter (0392) 444000. Photography and design by Andrew Nadolski, Exeter.

Printed on environmentally friendly paper. PR6/92

NATIONAL WATER RESOURCES STRATEGY - ENVIRONMENTAL ASSESSMENT

SCHEME SUMMARY SHEET - ROADFORD CONJUNCTIVE USE SCHEME

Objectives of the Scheme

The Roadford Reservoir Scheme was built to meet the forecast rising demands in the Plymouth, South West Devon and North Devon areas until well into the twenty first century.

Roadford follows Wimbleball and Colliford as SWWSL third strategic reservoir.

Date of Implementation

Construction started in 1986 and the dam was completed in October 1989 when filling of the reservoir started.

Physical Components of the Scheme

Roadford reservoir lies in the centre of a complex water resource development. It is designed to operate in conjunction with abstractions from the rivers Tamar, Tavy, Dart, Torridge and Taw as well as Burrator and Meldon reservoirs. Essentially, during wet periods water is abstracted directly from the rivers or smaller reservoir sources whilst during drier periods these abstractions are reduced and water is abstracted from Roadford instead. Water from Roadford is transferred by pipeline to North Devon and via the River Tamar to Plymouth and South West Devon.

Frequency of Operation

The frequency of the operation of the scheme is controlled by the prescribed flows in the Rivers Tamar, Tavy, Dart, Torridge and Taw and the amount of water remaining in Roadford reservoir.

Currently demands are such that the scheme is not being used to its full potential.

Hydrology: With/Without

The operating rules have still to be finalised. However, it is likely that flows in the Tamar system between Roadford and Gunnislake will be increased by releases from Roadford of up to 166 Ml/d.

Conversely unsupported abstractions at Gunnislake, mainly in the late Autumn and early Spring would reduce flow downstream of Gunnislake by about 50 to 100 Ml/d.

There would also be improvements to the flow regimes of the Tavy, Dart, Plym/Meavy, Torridge and Taw at low flows.

081 544 8500

To HUGH GOLDSMITH
Company HOWARD HUMPHREYS
From Alan Weller
Company NRA SOUTH WEST
FAX
Post-it Fax Note

Impacts: Perceived/Measured

Water Quality

Current quality only available as there was no formal requirement for pre/post scheme appraisals for this reservoir. No specific post impact studies have been undertaken by NRA SW as yet. However there was a public enquiry commitment requiring the developer to report on impacts 10 years after filling.

The reservoir is too new to sign off as not having measurable impacts.
Re-suspended material did cause some turbidity problems in the river soon after, affecting fishing mainly.

High manganese and sulphide levels were causing some difficulties downstream (EQS failures) during scour value testing, but this is now being managed by irrigating the first flush water in nearby woodland.

Fisheries & Recreation

The construction of Roadford Reservoir effectively drowned out several miles of spawning and nursery territory used by salmon, sea trout and brown trout. A mitigation programme to compensate for these losses is in place.

Since the construction of the reservoir salmon and sea trout do not penetrate as far into the Wolf system as they did before, stopping some distance downstream of the dam. This may be due to reduced flows, however, using surplus water special releases are made to enhance flows to try and attract adults into the Wolf system and to protect the juvenile stocks.

At high flows in the rest of the catchment the River Wolf may be running at compensation flow deterring migration into this part of the system whereas conversely under low flow conditions releases from the reservoir could attract fish into the Lyd system away from the main stem Tamar.

High releases from the Reservoir cause scour and interfere with fishing on the Wolf, Thrushel and Lyd system; particularly sea trout.

The Roadford scheme also impacts other river systems as follows:

River Plym
As part of the Roadford scheme, Burrator reservoir on the River Plym system will be put to greater use because of economies obtained from gravity feed from this reservoir. Consequently, spillage in late Autumn necessary for the migration of salmon to their spawning grounds in the River Meavy is likely to be reduced.

Additional drawdown on this reservoir will also have an effect on recreational activities such as boating and fishing.

River Tavy
The scheme involves additional abstraction on the River Tavy at Lopwell, just above the head of tide. It is considered that this could be detrimental to the movements of salmon from the estuary into freshwater and the situation

is being monitored.

River Taw
A new abstraction at Newbridge, just above the tidal limit in the river Taw will reduce flows into the estuary. This may have a detrimental effect on fish movements. These are currently being monitored.

Until 1995, the Exe/Taw transfer allows for the pumping of water from the River Exe at Exebridge over into the Molland Yeo and then down the River Mole and River Taw to the Newbridge intake. This transfer of water has been welcomed by fisherman on the Mole system as it enhances flows in the Molland Yeo and may encourage fish to penetrate further into the Mole system earlier in the year.

Abstractions at Leehamford and Taw Marsh; both headwater abstractions on the Taw system have had their licences reviewed as a result of the additional water supplied by the Roadford scheme with benefits to fisheries interests.

River Torridge
As a result of the Roadford scheme the compensation flow at Meldon reservoir has now returned to the standard Q95 level.

There are many aspects of the Roadford Scheme where the environmental impact is not yet fully understood. Extensive survey work is being undertaken to monitor fish movements in relation to flows, juvenile production and catch statistics.

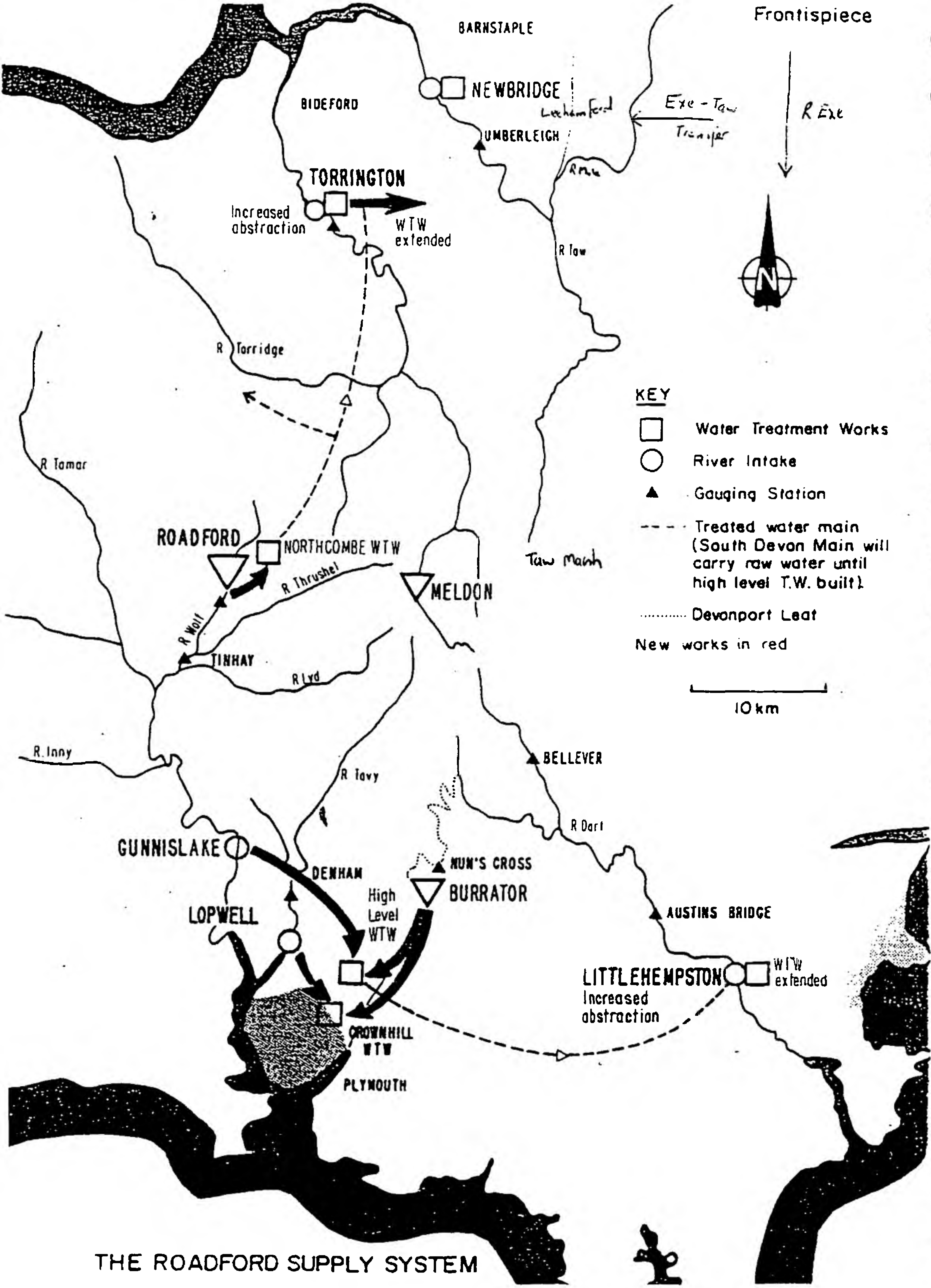
Roadford reservoir
Roadford reservoir has some effects on recreational fishing activities downstream, as mentioned above. The creation of the reservoir however, has provided an opportunity to develop a new brown trout fishery and proposals are in hand for other water sports.

The effects of the scheme on conservation issues is considered to be minimal within river systems. Where there are augmented flows there may be some minor effects from variations in water level, but on the whole enhanced flows will be beneficial.

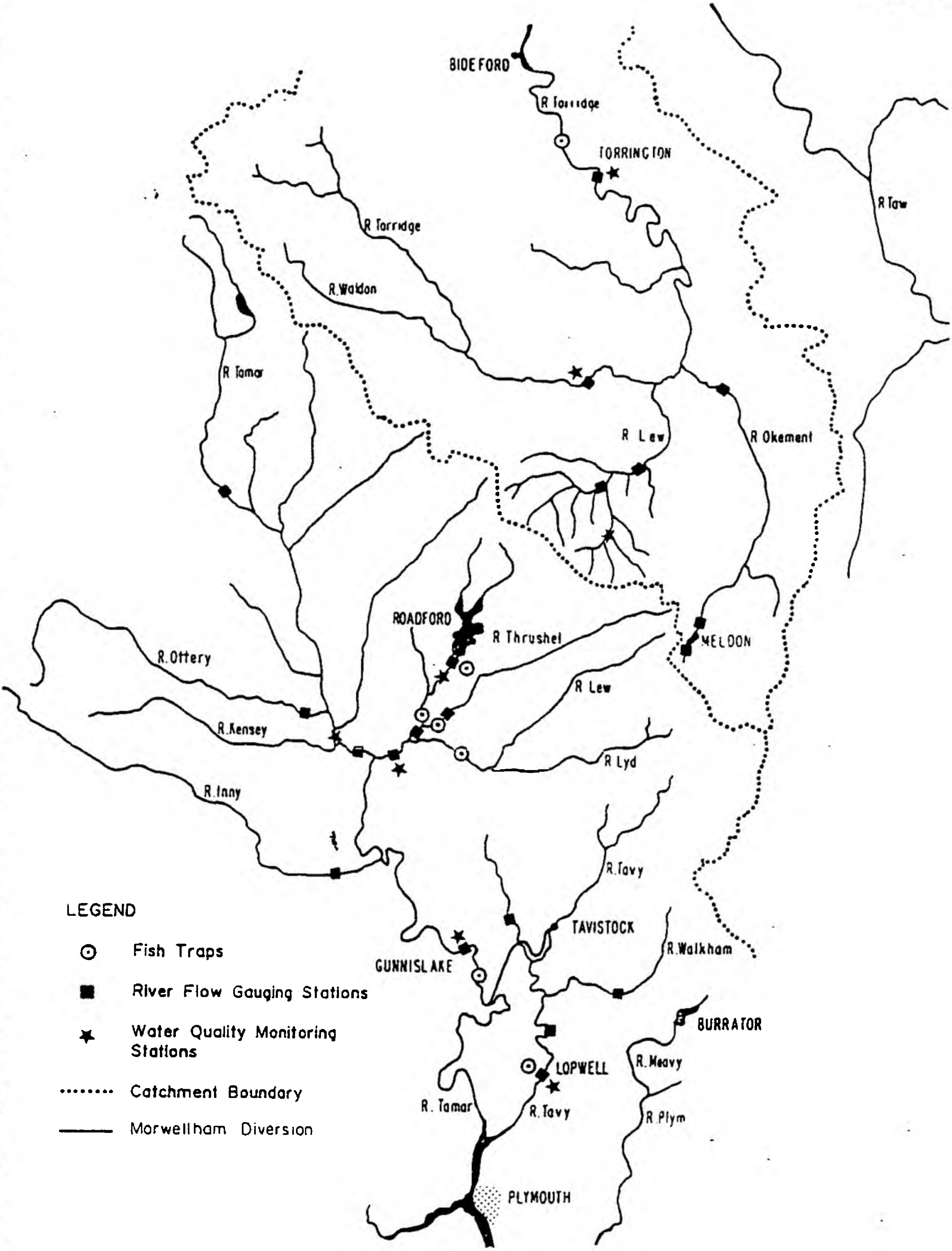
Within the reservoir site itself some value woodland and marshland habitat has been drowned out, together with an interesting archaeological site which was thoroughly explored before filling. The reservoir, which is now full, attracts a wide range of water birds and over a million trees have been planted along the margins to compensate for the loss of woodland species within the site.

References
SWWSL & NRA SW Roadford Operational and Environmental Study, Final Report Volume 1 January 1992.

Frontispiece



THE ROADFORD SUPPLY SYSTEM



LOCATION OF MONITORING STATIONS

NATIONAL WATER RESOURCES STRATEGY - ENVIRONMENTAL ASSESSMENT

SCHEME SUMMARY SHEET - COLLIFORD LAKE AND SIBLYBACK RESERVOIR SCHEME

Objectives of the Scheme

Colliford Lake is used in conjunction with Siblyback Reservoir to provide a major portion of the public water supplies in the Colliford strategic zone. This zone provides water for a major part of Cornwall.

Date of Implementation

Siblyback Reservoir was constructed in the late 1960's. The abstractions at Trekeivesteps, Restormel and Bastreet have been in operation since 1971. Impoundment of Colliford commenced in July 1983, the scheme becoming operational in July 1984.

Physical Components of the Scheme

The licenses that together make up this scheme are in places extremely complicated, with in some case interpretation of the conditions changing over time, in addition actual operation may have evolved away from these conditions.

Colliford Lake supplies water by direct supply to the De Lank and St Cleer water treatment works and by augmentation of the St Neots River and the River Fowey for abstraction at Restormel. It is used in conjunction with Siblyback reservoir which supplies water by augmentation of the Colliford River and the River Fowey for abstraction at Trekeivesteps and Restormel. Siblyback is also used to pump water to the Withey Brook for augmentation of the Bastreet intake.

The priority source for De Lank WTW is the natural flow in the De Lank River. When the natural flow is less than 0.011 m^3/s water is fed directly to De Lank WTW from Colliford.

The priority source for Bastreet WTW is the natural flow in the Withey Brook. When the natural flow is less than the prescribed flow water is pumped into the Withey Brook from Siblyback Reservoir.

The priority sources for St Cleer WTW are, the natural flow in the Fowey at Trekeivesteps and the direct supply from Colliford Lake. In addition water is released from Siblyback for abstraction at Trekeivesteps.

The priority source for Restormel WTW is the natural flow in the River Fowey. Second priority is the release of water from Colliford for abstraction at Restormel. Finally water can be released from Siblyback for abstraction at Restormel.

Frequency of Operation

The frequency of operation of both Colliford and Siblyback is controlled by the prescribed flows in the Rivers, Fowey and De Lank and the Withey Brook. As such the amount of use of different aspects will vary from year to year.

Hydrology: With/Without

Some hydrological data does exist on the St Neot River from 1972 to the present day. From this it is thought that it would be possible to assess the hydrological impact of Colliford Lake. This data however is not in a suitable format to enable this analysis to be undertaken int the current timescale. It is anticipated that further work on this strategic source will be undertaken later in the year.

Impacts: Perceived/Measured

- Low flows in the St Neots River are increased due to the augmentation releases to Restormel.

- Autumn and Winter flows in the St Neots River are reduced due to reservoir replenishment.

- Low flows in the Siblyback River are increased due to the augmentation releases to Trekeivesteps and Restormel.

- Autumn and Winter flows in the Siblyback River are reduced due to reservoir replenishment.

- A high percentage compared to the other two strategic sources (24%) of Annual Average Runoff can be used for PWS within the Fowey catchment.

Water Quality

Current quality only available as there were no formal requirement for pre/post scheme appraisals for this reservoir. No specific post impact studies have been undertaken.

Colliford Lake, soon after filling developed some problems related to humic material precipitating out (the floor of the lake had not had soil removed adequately), causing some problems in the St Neot River by depositing onto the stream bed.

In recent years blue/green algal blooms have been recorded (1991-93) causing problems for recreational use and for fish rearing in the lake.

Fisheries

Colliford Lake drowned out several miles of sea trout and brown trout spawning and nursery territory. The migratory elements are being compensated by a mitigation rearing scheme at Colliford Hatchery.

Spate flows in the St Neot River have been moderated by the construction of the Lake and this has influenced the migration of sea trout which no longer run as far as the dam site on this system. Releases from the Lake are governed by river flows at Restormel and in the Autumn when spate flows are sufficient for fish migration the St Neot River runs at compensation levels.

Releases from the Lake during low flow periods are considered generally beneficial in terms of flow but can have a detrimental effect on fishing. Peat coloured water released from the Lake reduces visibility which is a key factor in locating fish in the Fowey system. A study by David Solomon suggested that such colour was not disadvantageous to fishing provided anglers adjusted fishing methods.

During low flow periods, higher flows released from Colliford Lake down the St Neot River can sometimes provide a false lead for migratory fish at the St Neot/Fowey junction. This is further exacerbated by the abstraction at Doublebois Weir which bypasses the junction.

Spate flows below the Restormel intake are likely to have some effect on fish migration as flows will be unnaturally lower than normal

Recreation

The construction of the Reservoir has undoubtedly provided additional recreational facilities for fishing. The Reservoir is a popular brown trout fishery.

Conservation

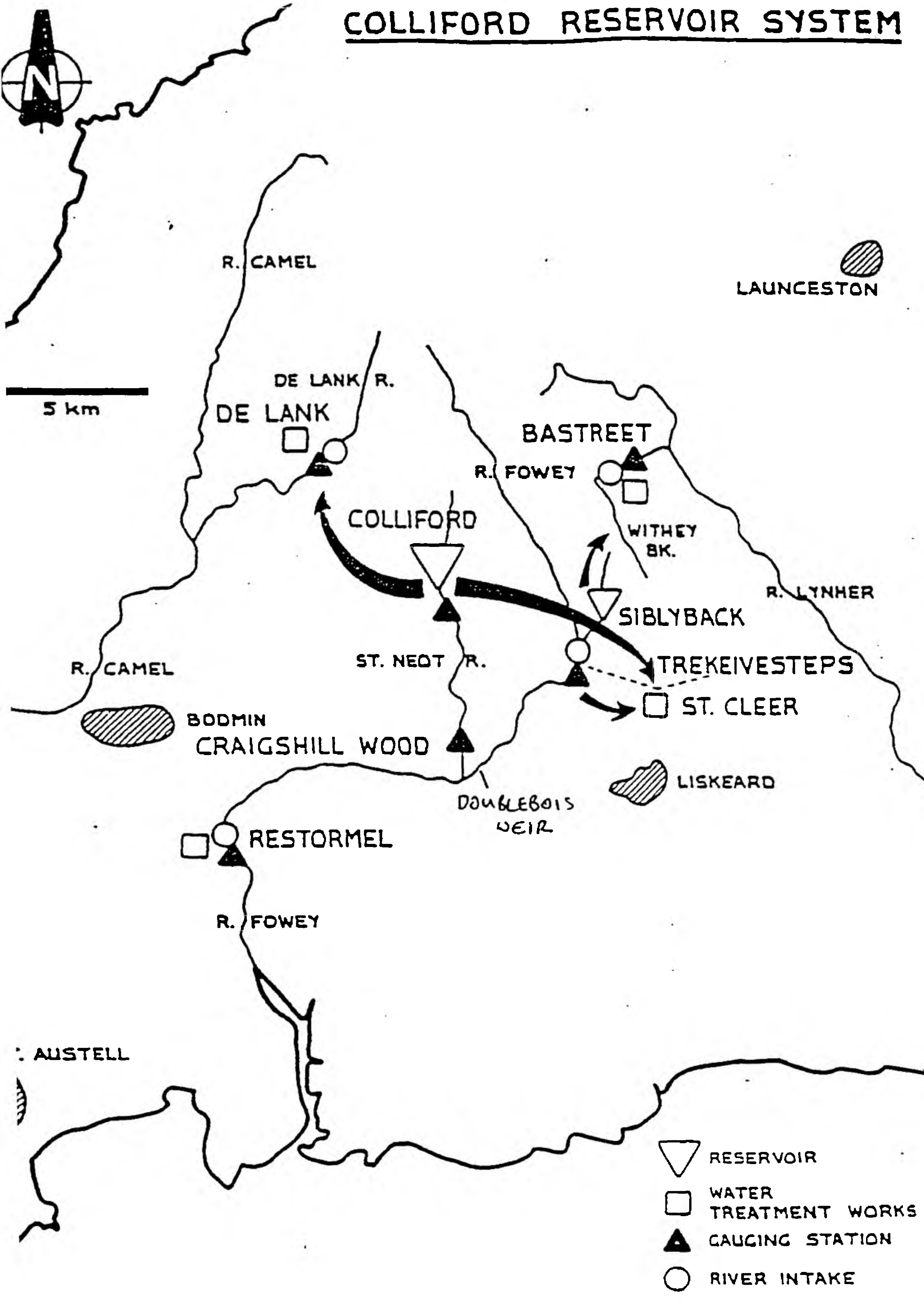
Considerable areas of natural moorland/marshland vegetation were drowned out by the construction of the Lake together with some archaeological remains. To a degree these have been compensated for by the numbers of wildfowl and wading birds attracted to the Lake since its construction.

References

Colliford Lake in Cornwall: From Promotion to Utilisation.

SWWSL and NRA SW, Colliford and Siblyback Reservoir Scheme, Document A3.

COLLIFORD RESERVOIR SYSTEM

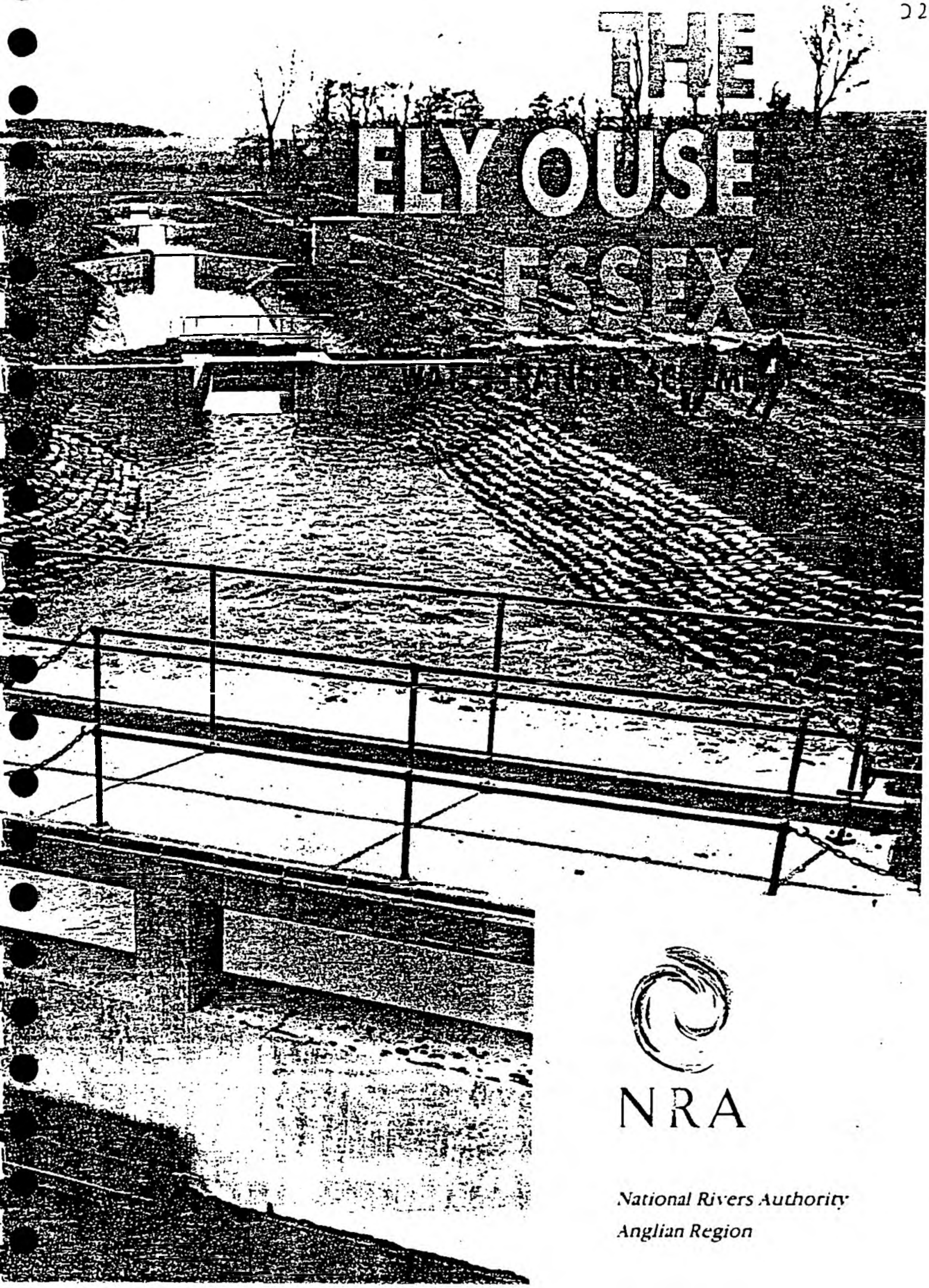


Outfall

ANGLIAN

32

THE ELY OUSE ESSEX WATER TRANSFER SCHEME



NRA

National Rivers Authority
Anglian Region

Essex Scheme

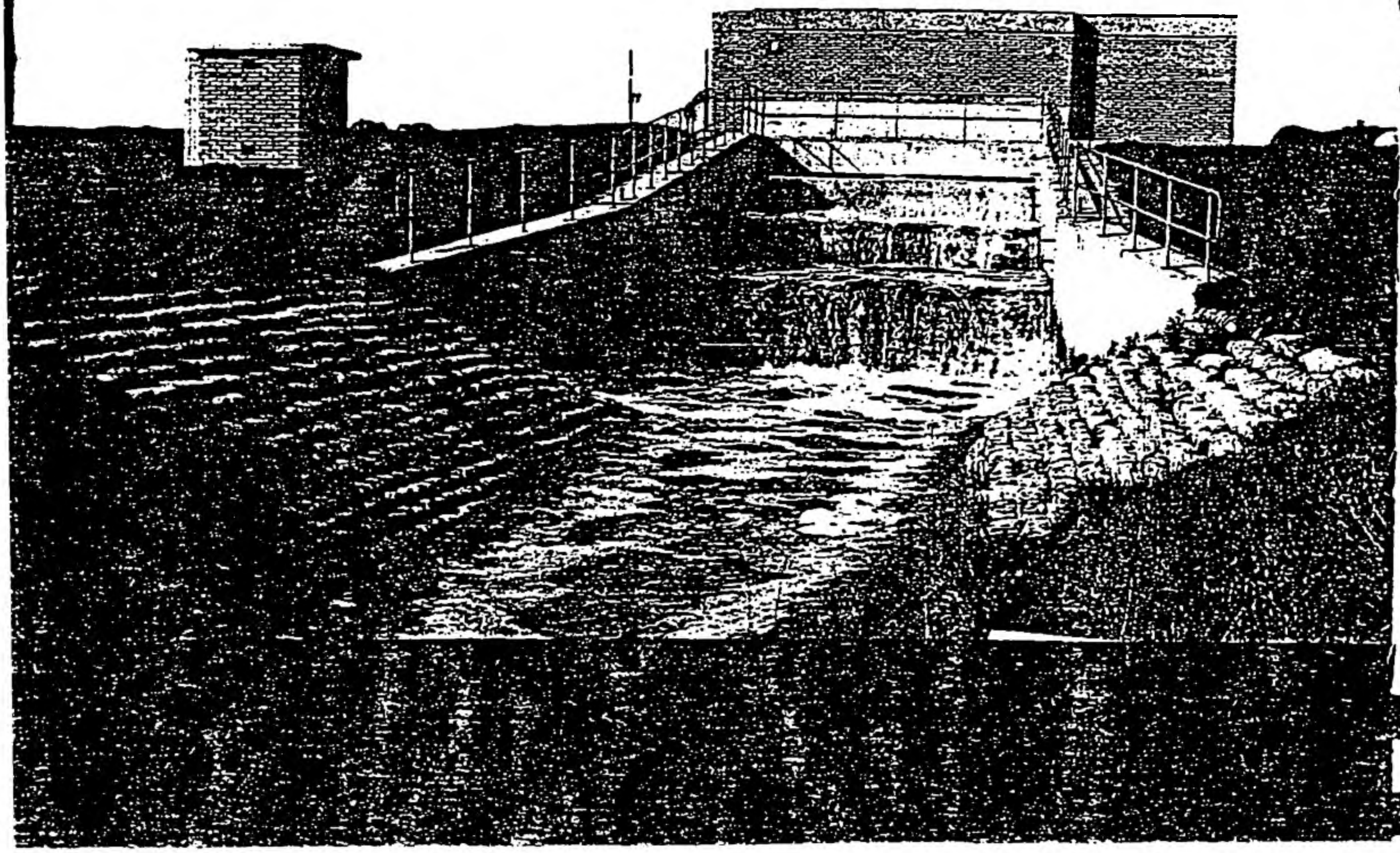
In 1964 the Ministry of Housing and Local Government Study highlighted the fact that expansion and development and the general population increase anticipated in the South Essex area could result in problems over water supply in the 1970s. The former Great Ouse and Essex River Authorities investigated a scheme to transfer surplus water from the Ely Ouse to head waters of the Essex rivers to increase their flows and make available extra water to the existing reservoirs in Essex, and the Ely Ouse–Essex Water Act 1968 was promoted jointly by the two Authorities. One great merit of the scheme was that it utilised existing reservoir capacity thus avoiding the loss of agricultural land to create new reservoirs.

The Ely Ouse River drains a catchment of approximately 3640 km^2 (1410 sq. miles) upstream of Denver and is fed by four main tributaries, the Cam, Lark, Little Ouse and Wissey. All these rivers are retained at a similar level downstream of Bottisham, Isleham, Hockwold and Stoke Ferry respectively, by the sluice at Denver at which point surplus water discharges into the tidal channel and reaches the Wash near King's Lynn.

This leaflet also describes the flood protection scheme at Denver which includes the Cut Off Channel on the eastern limit of the Fens. Under the Ely Ouse–Essex scheme surplus water from the eastern part of the catchment, which would otherwise be lost to tidal waters and eventually to the Wash, is transferred to the flood protection scheme Cut Off Channel at Denver, and by raising the level in this channel by 0·6 m at the impounding sluice the water is sent in a reverse direction in the channel to Blackdyke, Hockwold some 25 km to the south east. At this point water is drawn off into a tunnel 20 km long which terminates at Kennett. Pumps lift the water from the tunnel and through a 14·3 km long pipeline over the watershed to the River Stour at Kirtling Green. Part of this discharge is drawn off at Wixoe about 13·7 km downstream and pumped 10·3 km over further watersheds to the River Pant, through a pressure relief or balancing tank at the highest point.

The total distances of transfer from Denver to Abberton and Hanningfield reservoirs through aqueducts and improved river channels are approximately 141 km and 148 km respectively. For about two-thirds of this length use is made of existing watercourses.

Great Sampford Outfall



TECHNICAL DESCRIPTION

Two sluices on the Ely Ouse at Denver, one downstream and one upstream of a dividing sluice, transfer water into the Cut Off Channel. The downstream sluice will discharge a flow to maintain the required level in the Relief Channel, and the upstream sluice diverts the surplus water into the Cut Off Channel.

The Dividing Sluice is designed to enable the water level in the channel to be raised approximately 0·6 m, and thereby produce a reversal of flow, water is then abstracted at Blackdyke. In high floods the gates are raised to permit the channel to be used for its original flood protection purpose.

Blackdyke Intake

At the intake water is drawn from the Cut Off Channel and passed through coarse screens and self-cleansing bandscreens and a short length of 1·68 m diameter pipe.

Tunnel

The tunnel of approx. 2·5 m diameter was driven in the gault clay by mechanised digging shields and lined with precast concrete segments.

Kennet Pumping Station

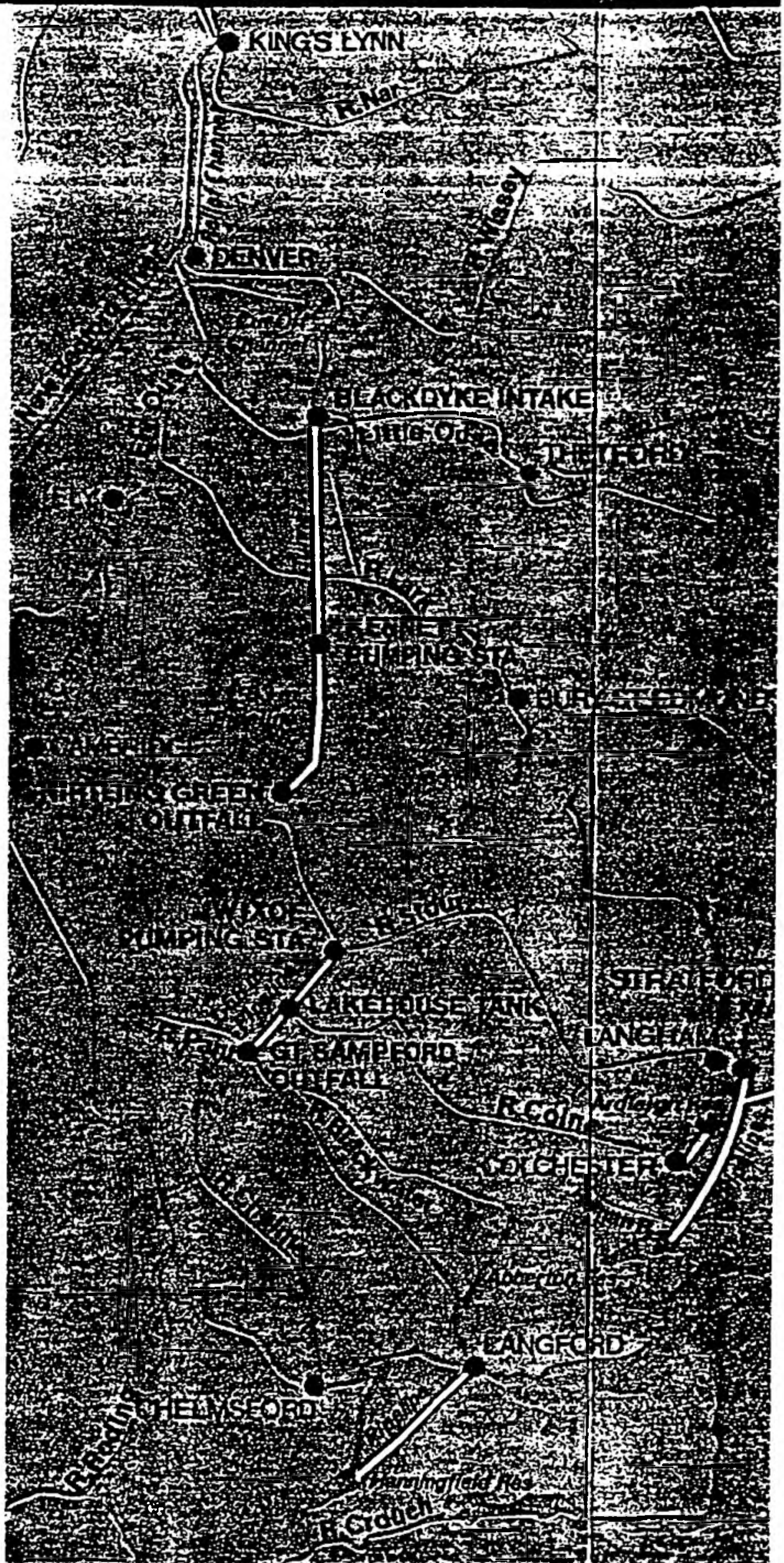
The main pumps are two vertical spindle 114 thousand cubic metres per day (tcmd) fixed speed borehole type pumps of 3500 hp each, set in the shaft cap and with groups of 4 and 3 impellers at depths of 51 m and 9 m from the surface respectively. Two submersible pumps of 23 tcmd fixed speed are provided for dewatering the tunnel and for supplementary flows. The pumps operate in an open well below ground level and are served by a 65-tonne Goliath crane.

Kennet–Kirtling Green Pipeline and Outfall

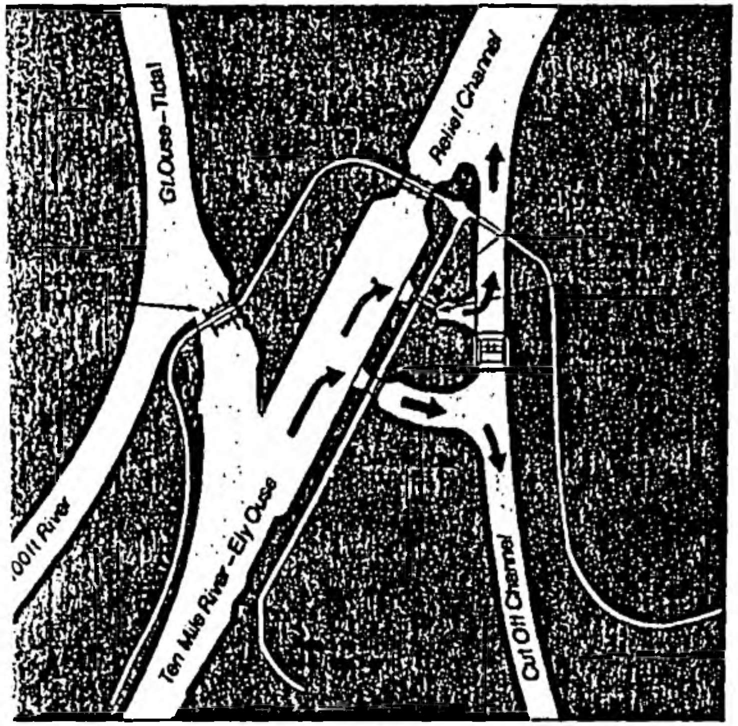
The 1·83 m dia welded steel main is 13 mm thick, bitumen lined and sheathed and cathodically protected. The pipeline is laid in trench with a minimum cover of 1 m or 1·2 m depending on the nature of the ground.

There are washouts at low points, and 'pigging' chambers at each end for swabbing devices. Anti-vacuum valves and air valves are provided for relief of negative pressures in surge conditions.

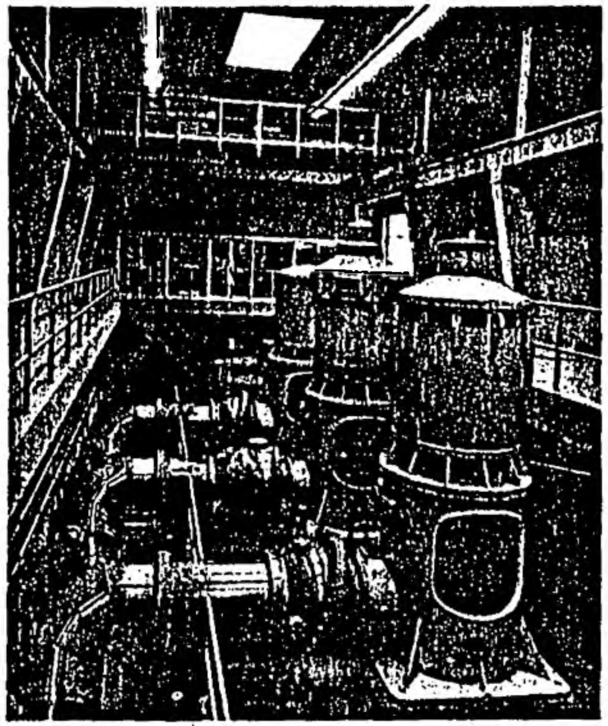
At Kirtling Green water discharges through a stilling basin structure before flowing in an open channel to the river.



The Transfer Scheme



The Denver Sluice Complex


Wixoe Pumping Station

Wixoe Pumping Station

Reasonably constant river levels are maintained by an automatic bottom hinged control gate.

Water is drawn from the River Stour via a settling pound and through self-cleaning bandscreens by two fixed speed 91 tcmd pumps and one variable speed 45 tcmd pump, all of which discharge into a 6·3 km long 1·68 m internal diameter pipeline to the balancing tank at Lakehouse Grove.

Great Sampford Outfall

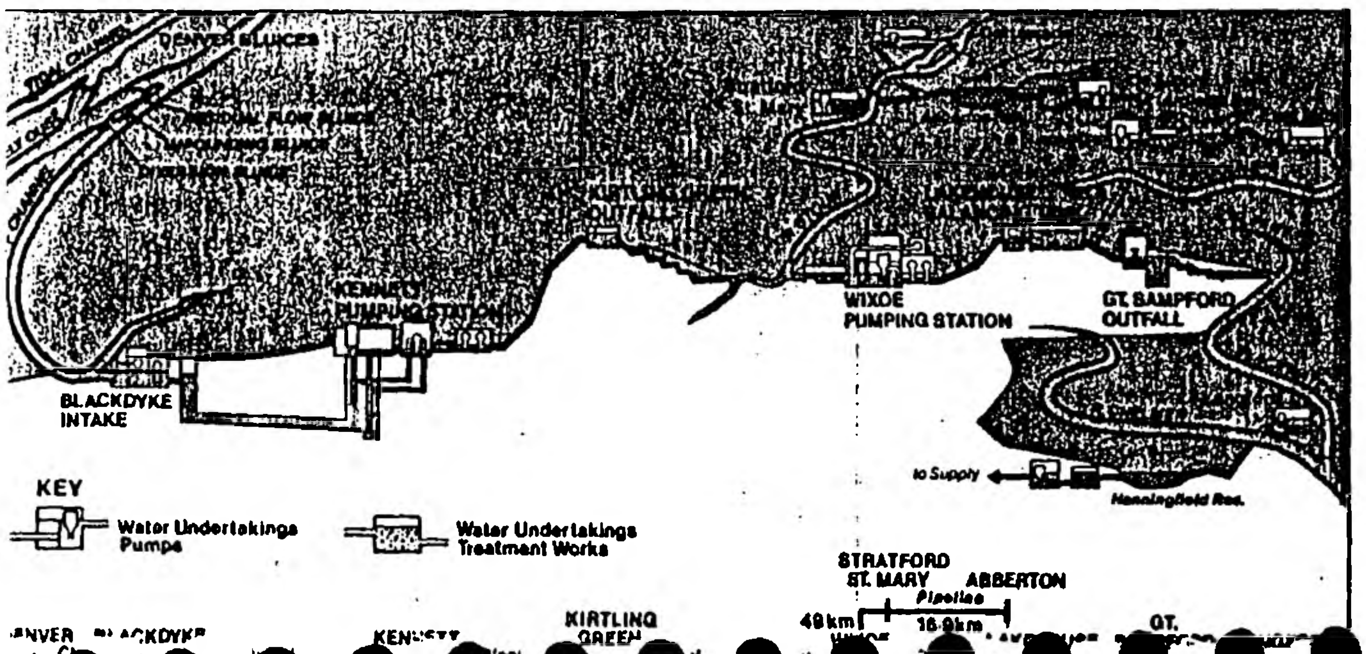
Water flows by gravity from the balancing tank to the outfall on the River Pant through a 4 km long 1·68 m dia pipeline.

Surplus pressure energy of the water is dissipated through two 227 tcmd vertical sleeve valves with 760 mm outlets submerged in a stilling pool. The water then flows down a stepped channel to the river.

Improvement to River Channels

16·8 km of the River Stour below Kirtling Green and 16 km of the River Pant (Blackwater) below Great Sampford have been improved to accept the increased flows by widening and deepening certain stretches and enlarging waterways through some bridges and mills. Ten new automatic control gates were constructed on the River Stour and one on the River Pant.

Note: 4·55 tcmd = 1 million gallons per day (mgd).



NRA

National Rivers Authority

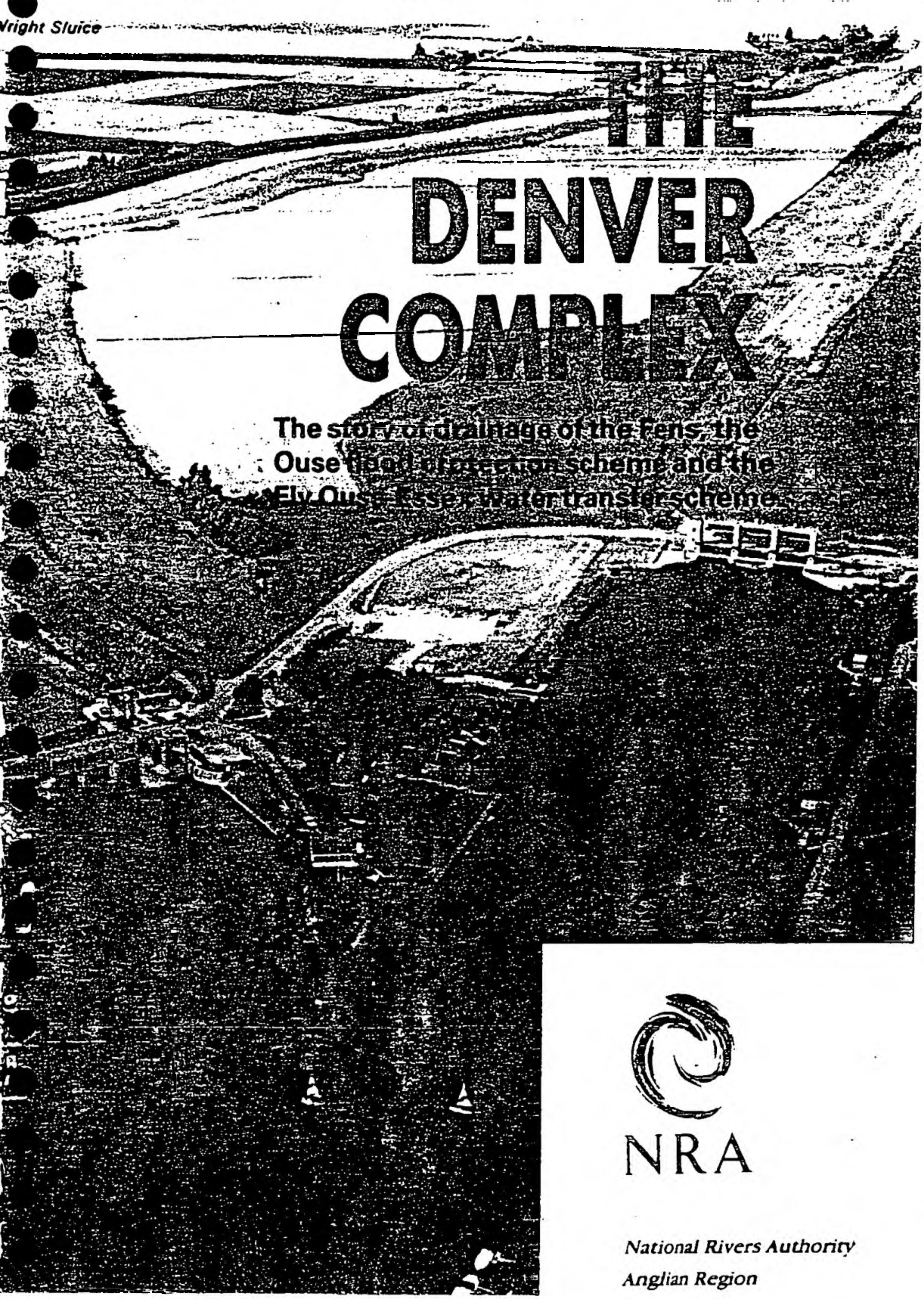
Anglian Region

Kingfisher House

Orton Goldhay

[illegible] PE2 07[illegible]

Wright Sluice



THE DENVER COMPLEX

The story of drainage of the Fens, the Ouse flood protection scheme and the Ely Ouse-Essex water transfer scheme

NRA

National Rivers Authority
Anglian Region

Fenland

In a massive arc around the Wash lies the great Fenland plain. Of the total area of England and Wales, only 5% is classified as first class agricultural land, and almost the whole of the Fenland falls into this category. Today, these are England's most prosperous agricultural areas, but their plenty has been hard won.

This is the Fen Country where land and water, down the ages, have been in such precarious balance that inches have measured the difference between fertility and flooding; where generation after generation has witnessed its livelihood engulfed by the wild waters of disaster. Only in the last two decades has the area finally been made secure by modern engineering and the application of millions of pounds of capital.

The post-glacial deposits in the shallow fenland basin are of three main types, the coastal silts of marine origin, the peats lying inland off the silt belt, and the fen clays deposited during a period of marine transgression.

To look back to the end of the 16th century when upland river and gale propelled tide alternated their push and pull across large areas, some were dry enough for summer pasture but submerged in winter, others squelching all the year round. Thus the scanty local population developed a special way of life. They were a people apart, among whom other Englishmen rarely ventured. Some were outlaws, most were laws unto themselves. They called themselves the "Breedlings".

The floors of their flimsy wattle and daub huts, thatched with sedge, were often awash, they slept on beds of reeds with Bullrush down stuffed into their pillows. For warmth they burned smokey squares of dried peat. They shook with ague, a mosquito-borne endemic malaria, in which fever and thirst alternated with severe pains in arms and legs. Their remedies were brandy and opium.

Militantly protective of their way of life, the Breedlings reacted with effective violence when the first overall plans for draining the entire fen area were announced in the 17th century. Battle they did, and for many decades sluice gates and other mechanisms installed according to the new designs required armed guards for protection, but even these were not always enough to save them from the Breedlings wrath.

In 1630, Francis, 4th Earl of Bedford, commenced the first major attempt to drain the Fens, and was joined by thirteen associates or "Adventurers". The work was not be adjudged complete until 1652. Bed engaged as engineer the just-knighted Cornelius Vermuyden, a Dutchman, fami with Dutch methods of keeping out the who had already demonstrated his skill drainage works at Hatfield Chase in Yo shire.

Vermuyden was to design and superv the work, which consisted principally of making of two new straight cuts – the and New Bedford rivers, from Earith Salters Lode on the tidal River Ouse, t cutting off the loop of the river through and shortening the distance to the sea ten miles. A flood storage reservoir of 5 acres was created between the two ne rivers, and embankments built to con flood water and tides.

In 1631 the first of the great cuts, know as the Old Bedford River, was dug, seve feet wide and twenty-one miles long, fr Earith to Salters Lode on the tidal river. sluice at its upper end regulated the amo of water diverted from the river's ordin course, and a Tail sluice resisted inflow fr the tidal water and the sea.

However, in the 1640's man-made de truction was an even more present dan than the waters. The western rim of the F country became an active theatre of the C War and in its confusion the Breedlings s and took their opportunities.

When Cromwell took control of gove ment after the end of the war, he promp set William, the recently acceded 5th Earl Bedford, and Vermuyden to work aga During the 1650's a vastly extended netw of cuts and drains and sluices was com pleted. Parallel to the Old Bedford Rive new river was cut, called the New Bedf River, or Hundredfoot, and in 1651 the fir Denver Sluice was constructed across

Ely–Ouse at the lower end of the Hundredfoot River. This excluded the tidal water from the South Level Rivers and turned it up the Hundredfoot – it was, in fact, the beginning of all year round control.

In 1713 disaster struck again when a combination of high tides and exceptional floods burst Denver Sluice. Once again the tides could flow unchecked into the South Level rivers, land was inundated, much of it became derelict, and incursions of the tide were frequent. In fact in 1715 a sturgeon measuring 7 ft 8 in long was captured in Thetford Mill Pool. It was obvious that Denver must be rebuilt, and in 1750 it was rebuilt by Labelye, a Swiss engineer.

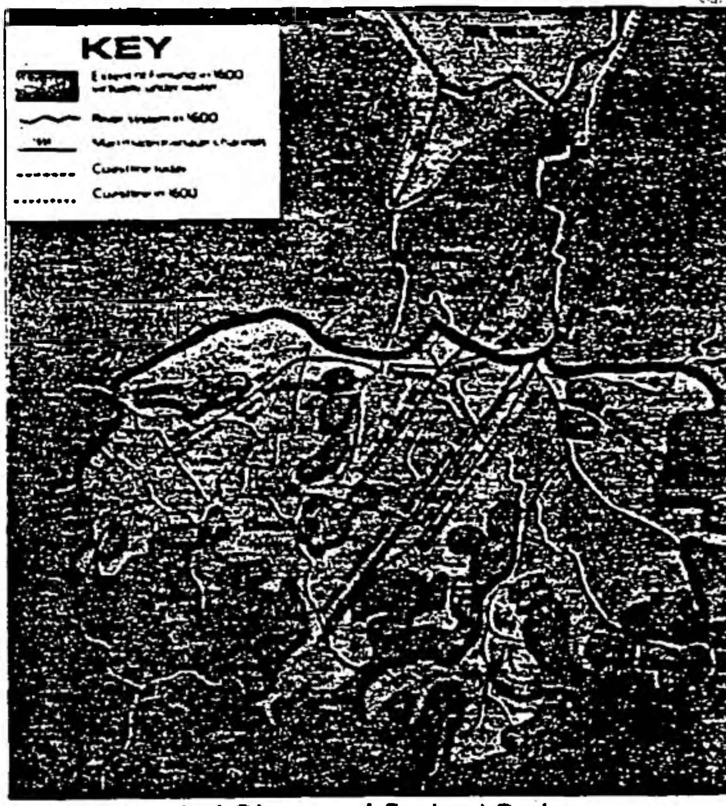
Labelye's work was to last well, in fact, the sluice which he had constructed was to remain in use until the last construction by Sir John Rennie in 1834. This was to give three main sluice-gates, which exist today in their original position, but at that time the upstream gates were not, as today, vertical lift gates, but were in fact, pointed wooden doors. In 1848 the Middle Level Main Drain was completed, much of it with a 50-foot bed width, and an outfall sluice at St Germains, into the tidal river.

During the 18th century work was continued. Mills were first used to drain the land effectively, only once again to cause a new problem when the Black Fen fields began to shrink away from the channels that drained them. Small mills delivered the water into small drains, and then further along a larger Mill would lift it into a canal, and finally the largest Mill of all would be used to lift it into the river.

The moisture content of waterlogged peat may be as much as 800% and when it is drained the immediate effect is a shrinkage of the top layer from which the water has been abstracted. This initial shrinkage may be more than a foot in the first year. This is followed by the oxidation of the dried surface, which results in further wastage. Loss from this cause, which continues so long as the peat is dry, may be one or two inches a year.

The Black Fens gradually became an upside-down world with rivers higher than the surrounding land, and thus began the separation of the fenland drainage network into two systems, a high level system carrying the upland rivers through the fens and low level systems carrying the drainage water to the mills or pumps.

During the 1930's and 1940's, due to

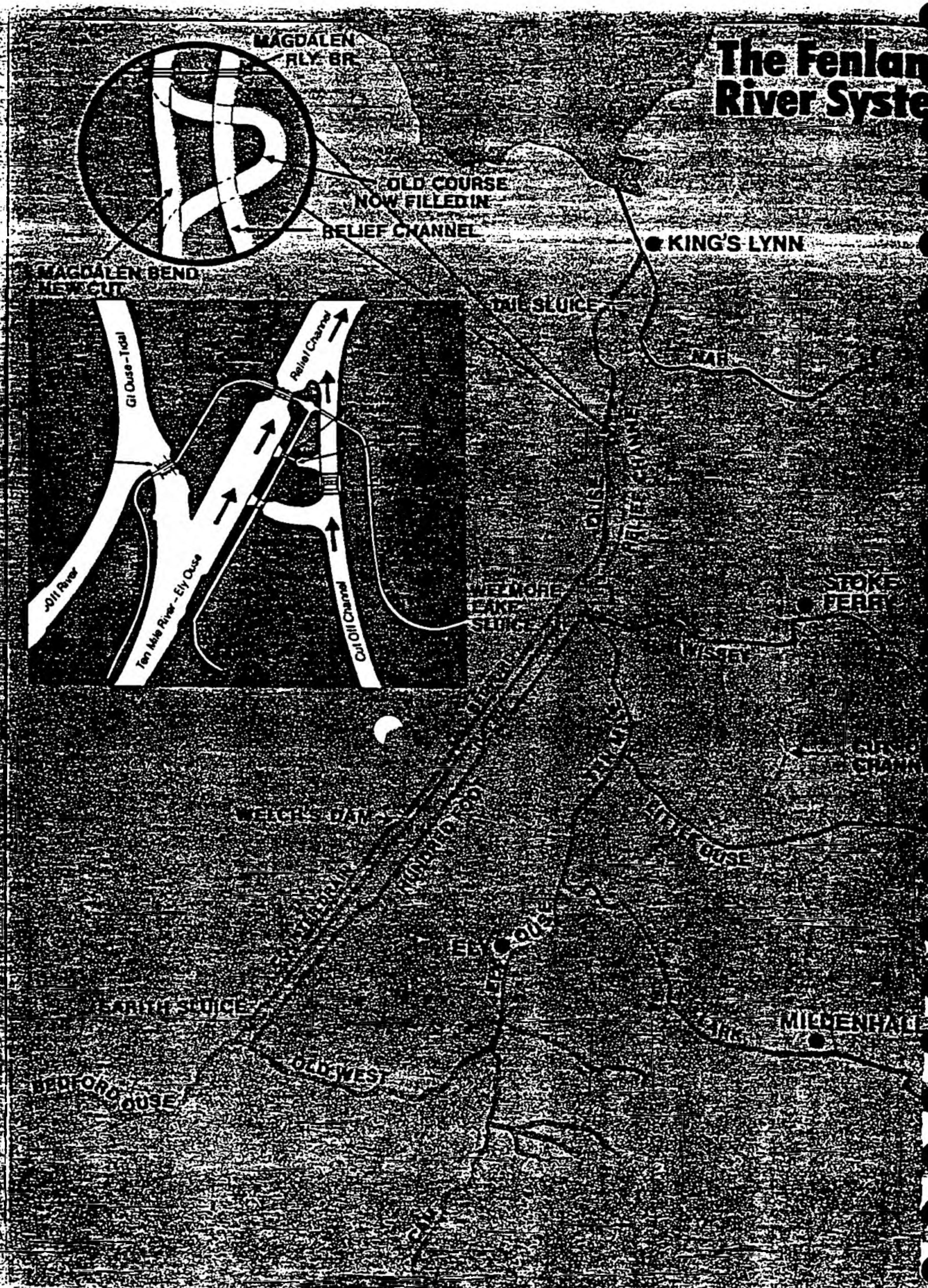


Historical Diagram of Fenland Drainage

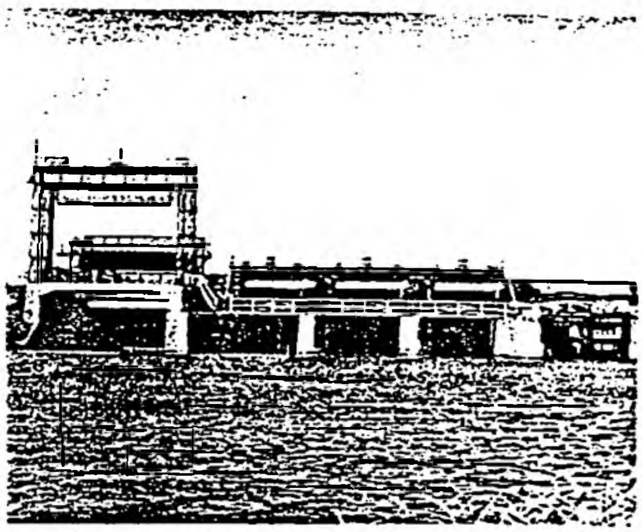
modern diesel and electric pumping machinery, there was no technical difficulty in providing good fen drainage, and the problem has accordingly resolved itself into the protection from flooding of the Fenland from overtopping, or breaching, of the flood banks. To counteract the continuous sinking, the flood banks had to be continually raised to give an adequate degree of freeboard, nearly 1 ½ million pounds being spent on this work between 1930 and 1954, without, however, really solving the problem. Major floods occurred in 1936, 1937 and 1939, after which the former Great Ouse Catchment Board called in Sir Murdoch MacDonald and Partners to prepare a report. The subsequent report proposed a Great Ouse Flood Protection Scheme designed to increase the freeboard of the flood banks in the South Level over maximum flood level, not by raising them, but by reducing the flood level itself. This scheme was, however, shelved because of the intervention of the second Great World War.

In 1947 occurred the greatest flood of which there is any record, when 40,000 acres of Fenland were flooded. The 1947 flood discharge was twice as great as that of 1937 and as a result Sir Murdoch MacDonald and Partner's proposals were revised based on a flood about 5% greater than that of 1947 coinciding with a period of Spring tides. In 1949 the Great Ouse River Flood Protection Bill was passed by Parliament.

The Fenlan River Syste



The Flood Protection Scheme



Denver Sluice

Parts of the fenland are as much as 1·5 m below mean sea level; high flood level is [illegible]·5 to 4 m above it.

Our problem is not fen drainage, it is the protection of the fens from flooding by the failure or overtopping of the river embankments.

This suggests that the remedy is to make the flood banks high enough and strong enough to contain the floods. Alas, the solution is not quite so straightforward; another kind of fenland soil comes into the picture – the "buttery clay". "Buttery clay" is an apt description of the soft, silty clay which overlies most of the fenland floor beneath the upper coating of peat or silt.

From surface level to the hard Kimmeridge clay, gault or chalk may be as much as 5 or [illegible] m; even more in a few places. The flood embankments rest, one is inclined to say they float, upon the peat and buttery clay layers. This affects them in three respects, liability to sinking, stability, and seepage underneath them.

The flood banks sink as the peat and the soft clay consolidate slowly under their weight. As they sink the safe margin above flood level (freeboard) diminishes and they have to be heightened. The weight of the clay added to them in the heightening starts off a new sinking process – and so on.

It is obvious that continually heightening the banks will not provide the solution to the problem, which has been the subject of arguments, counter arguments and disputes at intervals since the 17th century, although the real nature of the problem was not appreciated by the numerous writers on the subject. The main problem was that the flood waters were not "getting away", and it was not realised that Sir Cornelius Vermuyden had given the solution nearly 300 years earlier.

The obstacle to the discharge of the South Level waters through Denver Sluice is that in times of flood the water level from the old and new Bedford–Ouse outside the sluice was higher than the waters coming from the Ely–Ouse and its south level tributaries. However, the low water level at King's Lynn under high flood conditions is about 3·5 m lower than at Denver. Therefore, by by-passing the Denver Sluice and bringing the point of discharge to King's Lynn, advantage can be taken of this lower water level to enable the flood waters from the South Level rivers to get away. A relief channel was, therefore, cut from Denver with sluice gates at each end. To ease the flood level in the Ely–Ouse itself a cut off channel from the River Lark near Mildenhall crossing the River Little Ouse and the River Wissey takes flood waters from all three rivers and conveys them to the Relief Channel for discharge at King's Lynn.

When the incoming tide rises the tail gate sluices at King's Lynn close and the outflow of the flood water ceases. The water is then contained in the Relief Channel and it rises inside the gates until the tide once again falls, the gates open and the discharge of the flood water is resumed.

In addition to the new channels, the Ely–Ouse River was widened to increase its capability. The basic principles of this scheme were in fact put forward by Vermuyden in 1638, and he produced a drawing of the scheme in 1642. It was, however, over 300 years before the same conclusions resulted in the scheme being carried out. With the completion of the scheme in 1964 the old problem of how to move excess water from the Fens into the sea has largely been overcome.

The Flood Protection Scheme

Parts of the fenland are as much as 1·5 m below mean sea level; high flood level is 3·5 to 4 m above it.

Our problem is not fen drainage, it is the protection of the fens from flooding by the failure or overtopping of the river embankments.

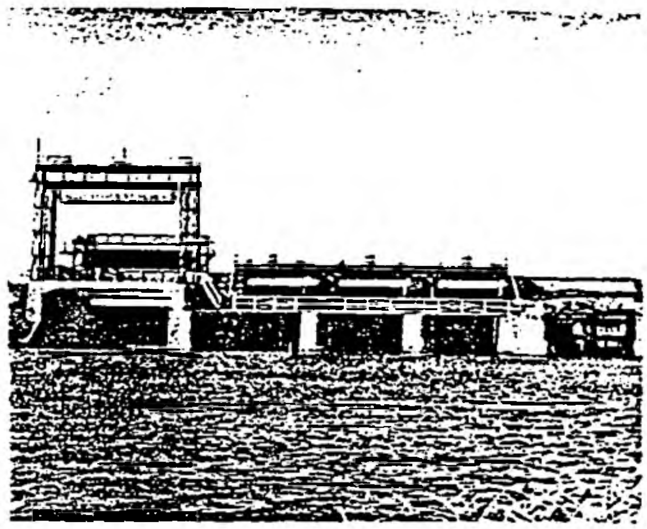
This suggests that the remedy is to make the flood banks high enough and strong enough to contain the floods. Alas, the solution is not quite so straightforward; another kind of fenland soil comes into the picture – the "buttery clay". "Buttery clay" is an apt description of the soft, silty clay which overlies most of the fenland floor beneath the upper coating of peat or silt.

From surface level to the hard Kimmeridge clay, gault or chalk may be as much as 5 or 6 m; even more in a few places. The flood embankments rest, one is inclined to say they float, upon the peat and buttery clay layers. This affects them in three respects, liability to sinking, stability, and seepage underneath them.

The flood banks sink as the peat and the soft clay consolidate slowly under their weight. As they sink the safe margin above flood level (freeboard) diminishes and they have to be heightened. The weight of the clay added to them in the heightening starts off a new sinking process – and so on.

It is obvious that continually heightening the banks will not provide the solution to the problem, which has been the subject of arguments, counter arguments and disputes at intervals since the 17th century, although the real nature of the problem was not appreciated by the numerous writers on the subject. The main problem was that the flood waters were not "getting away", and it was not realised that Sir Cornelius Vermuyden had given the solution nearly 300 years earlier.

The obstacle to the discharge of the South Level waters through Denver Sluice is that in times of flood the water level from the old and new Bedford–Ouse outside the sluice was higher than the waters coming from the Ely–Ouse and its south level tributaries. However, the low water level at King's Lynn under high flood conditions is about 3·5 m lower than at Denver. Therefore, by by-passing the Denver Sluice and bringing the point of discharge to King's Lynn, advantage can be taken of this lower water level to enable the flood waters from the South Level rivers to get away. A relief channel was, therefore, cut from Denver with sluice gates at each end. To ease the flood level in the Ely–Ouse itself a cut off channel from the River Lark near Mildenhall crossing the River Little Ouse and the River Wissey takes flood waters from all three rivers and conveys them to the Relief Channel for discharge at King's Lynn.



Denver Sluice

When the incoming tide rises the tail gate sluices at King's Lynn close and the outflow of the flood water ceases. The water is then contained in the Relief Channel and it rises inside the gates until the tide once again falls, the gates open and the discharge of the flood water is resumed.

In addition to the new channels, the Ely–Ouse River was widened to increase its capability. The basic principles of this scheme were in fact put forward by Vermuyden in 1638, and he produced a drawing of the scheme in 1642. It was, however, over 300 years before the same conclusions resulted in the scheme being carried out. With the completion of the scheme in 1964 the old problem of how to move excess water from the Fens into the sea has largely been overcome.

OM 1a

FAX MESSAGE

NRA

National Rivers Authority
Anglian Region

FAX DESTINATION NUMBER

COMPANY NAME HOWARD HUMPHRIES

FOR THE ATTENTION OF HUGH GOLDSMITH

SUBJECT MATTER TRANSFER IMPACT

FROM CAMERON THOMAS

NUMBER OF SHEETS TO FOLLOW 7

IF PART OF THIS MESSAGE IS MISSING OR ILLEGIBLE, PLEASE TELEPHONE

Regional Headquarters
Kingfisher House
Goldhay Way
Orton Goldhay
Peterborough PE2 0ZR
Tel. (0733) 371811
Fax: (0733) 231840

Transfer and augmentation scheme tend to work only during dry periods hence with / without hydrology concepts fairly meaningless.

Don't lose sight of opportunities arising from transfer works eg to flush pollution, flush blanket weed during dry periods, controlled releases for canoeing

C. J. Thomas 17/6/93

NATIONAL RIVERS AUTHORITY: ANGLIAN REGION

PERCEIVED / MEASURED IMPACTS OF TRANSFER SCHEMES

The attached list summarises obvious perceived / alleged impacts: beware many have not been critically substantiated.

See also attached note (extract from a drought impact report, this section deals with impact of Ely Ouse - Essex Scheme).

Geomorphology

Upper reaches have been "improved" to cope with transfer rates: some local erosion particularly around outside of bends and in parts of river bed (no erosion evident in lower reaches?).

TWA Scheme transfers potentially silt laden water from tidal reaches of Trent to Torksey canal (BWB) who receive payment for dredging (although little evidence that it actually occurs?).

Hay field flooded when high rate transfers started suddenly at a time of significant weed growth (& hence reduced channel capacity).

Other Physical Impacts

Periods of sustained uniform un-natural high flows

Periods of rapidly variable flow (particularly during pump testing)

Both accompanied by corresponding levels.

Repair & maintenance of bridges gates etc cannot be carried out during the summer as normal because of unusually high flows.

Operation of gates and sluices:
- can automatic gates cope; do they react correctly
- unpredictable flow times (particularly on heavily managed rivers); are gates always set correctly?
- riparian owners often react erratically and inappropriately to changing flows / levels
- NRA effort on adjusting gates under our control

Caught out at least once by pumping at high rates during unforecasted heavy rain (minor local problems)

Beware i) river management practice often assumes transfer water will always

be available - in practice pumps fail etc...
ii) when transferring from a river which itself is supported there will be time you get your sums wrong: results in falling flows / levels, saline intrusion etc...

Water Quality

Major impact can be transfer of algal rich water to low algae river & consequent changes.

Relatively rapid changes in chemistry and / or temperature particularly if augmented at different times with both ground and surface water.

Many quality impacts as might be predicted.

Nutrient rich water into nutrient poor river.

One incident during 70's of transferring trace contaminant which killed irrigated tomato crop.

Some MAFF concern about possibility of transferring sugar beet rhizomania (particularly if donor river contains washings from beet factory) unresolved. Similar concerns at one stage about potato eelworm (?).

Concern about transferring pollution: automatic quality monitors?

Water trapped in system when no transfers: oxygen sag, anaerobic conditions, what do you do with it when you start pumping.

Discharge consents: do you set them assuming transferred water is available: what happens if you do and it isn't.

Local problems from groundwater augmentation boreholes: one abandoned due to iron content (ochre), another slightly high in sulphide which has sterilised discharge ditch (fortunately a field drain which is usually dry).

Navigation / Recreation / Amenity

See physical impacts.

[illegible]

Macrophyte scour in upper reaches of supported rivers.

Anything which affects macrophytes (scour, turbidity etc) affects entire ecosystem.

Seeding of rivers by algae, fluctuating clear / turbid water conditions hence changes to light intensity and macrophyte growth.

Conservation / Terrestrial Ecology

Switching off transfers alleged to impact on bird nesting success.

Fisheries

High sustained flows affect angling.

High rates of pumping can affect spawning (eg pumping at high rates from March to June coincided with cyprinid spawning season).

Clear / turbid conditions affect fish behaviour and angling.

Fish attracted into supported tributaries (particularly borehole support) left stranded when switched off.

Transfer of alien eggs / larvae / fry etc (eg zander?).

Other Comment

Transfer and augmentation scheme tend to work only during dry periods hence with / without hydrology concepts fairly meaningless.

Don't lose sight of opportunities arising from transfer works eg to flush pollution, flush blanket weed during dry periods, controlled releases for canoeing.

C. J. Thomas 17/6/93

generally above those of the non flood natural periods. In "natural" months, it is therefore probable that reasonable angling conditions were experienced for at least some of the time, which may not have been true at all in the "transfer months". Consequently, the pattern of anglers' complaints is quite compatible with the flow regimes experienced.

Given the scale at which transfers can occur, it is inevitable that river control structures have to be adjusted to cater for marked changes in rate. Many of these structures are old mill works, which have to be adjusted manually. There is clearly an imperative to ensure that control works do not restrict transfer flows, and lead to consequential upstream flooding. The problem of manual adjustment, and the resources required to accomplish it, are greatest if rate changes are frequent.

Figures 60-61 illustrate how flows in the Stour and Blackwater responded to rapid rate changes; both the figures commence with little if any transfer flow. Control structures were opened to coincide with the commencement of transfer, and the first recorded peaks in flow represent the release of water which results. Flows then recede again until the transfer water arrives. Figure 60 clearly shows that the second flow spikes, representing transfer water from a 24 hour pump test, arrive progressively later at the downstream stations, as would be expected. The figure also shows that the peak flow generated declines downstream; the spikes become flatter but of longer duration in the lower reaches. Two problems arise as a result. Firstly, gates throughout the river are generally set to match the pump test rate rather than the lesser flow they actually experience; secondly, the gates are open at times when flows are not continuously boosted by augmentation. The impact of both is the same; impoundment levels upstream of control structures drain down to much lower levels.

Figure 61 shows two flow spikes followed by a plateau. The first spike is gate opening, and the second the arrival of transfer water. However, the pumps were stopped again (for maintenance by contractors) after only a few hours run, before being permanently restarted about the same time later. Permanent running gave the ultimate flow plateaus. Gates were not reset to match these changes with the result that two periods of marked drain down upstream of structures were followed by a period of very high flows. This incident, and others like it, gave rise to significant levels of complaint about river regimes. Once again, the flow patterns observed are compatible with the nature of the complaint. Problems of this type are still more serious where old structures show leakage, and are not necessarily capable of retaining the head that the degree of gate opening would allow.

The difficulties described so far are concerned mainly with angling, which is inhibited or prevented by the circumstances described above. However, concerns were also expressed about the effects on the fish themselves, and on their invertebrate food resources. Apart from high flows and fluctuating levels, these revolved around the impact on habitat of increased channel erosion and loss of macrophytes, the seeding of the rivers by algae from the Ouse (causing turbid and very brown coloured water), the introduction of GOGWS or SAGS groundwater into the system (causing very clear water), the apparent fluctuations in water quality which stem from these factors, and the ability of the fish to spawn successfully in the face of peak transfer flows. (Unfortunately, the main spawning season for coarse fish runs from March to June, when transfers are frequently at a very high rate.)

All of these factors are potentially real threats to both the fish stocks and to the river environment as a whole, although there is no evidence to date to show that any quantifiable harm has occurred. The routine 3 year fishery survey programme will in due course show if any major stock changes have been precipitated, but cannot define all of the possible impacts.

Plates 1-4 (all taken in March 1993) show very clearly that the headwaters of the Pant/Blackwater have been physically affected by macrophyte loss, scouring and erosion, but there is no measure of how important this may be. Similarly, the seeding of the headwaters by algae is believed to impinge on water quality, and certainly has a visually very obvious effect. The brown and turbid water caused by algae may shade out macrophyte growths, and have far reaching consequences for the river ecosystem. To date, none of these matters have been adequately investigated, although they are the subject of a current research proposal.

A meeting was held with anglers's representatives at the North Essex District Office in July 1992, which was very helpful to both sides in achieving an understanding of the other's position. The anglers recognised the special importance of water resources under the drought conditions prevailing, whilst the NRA learnt a lot about the serious impact of poor and variable angling conditions and results on club administration, membership and financial viability. Closer liaison during major transfer periods was recognised to be potentially helpful by all parties, whilst in the long term, it was felt that there was scope for improving the operation of the scheme particularly by better control of flows and levels.

8) <u>Impact on other freshwater biota</u>

8.1) <u>Biological quality of watercourses</u>

Routine assessment of the biological quality of watercourses between 1989 and 1992 showed that a number of sites sometimes failed to reach their target standards (measured by the Lincoln Quality Index - LQI) as a result of the drought conditions. These are listed in Table XXI, which gives details of sampling dates, LQI values achieved, sampler's comments and whether or not the sample met its target standard.

In most cases, Essex catchments' sites (including the River Stour and tributaries) failed to reach their LQI targets because of low flows. Stagnant pools were formed at some locations which became silted up and discoloured by algae (Eg the River Pant 70m downstream of Great Sampford Bridge, and Bumpstead Brook at Watsoe bridge). Others became overgrown by macrophytes, with a consequent loss of habitat variety and hence fauna (Eg the Denston tributary of the River Glem at Assington Green Road Bridge, and Salary Brook at Blue Barns Farm). By the Autumn of 1990, five sites had dried out completely, with the (temporary) loss of all normal stream biota. These were the River Stour at Sipsey Bridge, Toppesfield Brook at the A604 Bridge, the Hawkedon tributary of the River Glem at Hawkedon Hall, the Mardyke East at Harrow Inn, and the West Tilbury Main Drain or by upstream migration is likely to have taken place as flows returned. No major mortalities are known to have occurred on rivers as a consequence of the drought.

What is not clear from the Tables is the longer term implications for river fish stocks. In some cases, for example the River Burn in Norfolk (section 3.3), survey work has already shown that the populations have been significantly affected. Both salmonid and cyprinid stocks appeared to be largely extinct, leaving eels as the dominant species. Recovery from this position will be inhibited by the lack of breeding stock, and it is probable that artificial restocking will be required to restore the fishery once flows have returned to normal. Similar circumstances (and prognostications) may well apply to the Lothingland Hundred River in Suffolk, which was affected by saline incursion as well as low flows worsened by licenced abstractions. On the Upper River Colne the loss of fish stocks under weed cover was concentrated between Mill structures which probably impede fish movements and hence recolonization. Once again, this could delay or prevent any natural recovery.

On a more positive note, very strong year classes of several species of fish were found after the drought years of 1975 and 1976. Some of these fish are still in evidence today. The low flows and high temperatures prevalent at the time were obviously very favourable to fry survival and growth, a factor which represented a considerable boost to the fish stocks of the late 1970's. It appears highly likely that 1989 and 1990 would have been similarly favourable, on account of their excellent summers. There is already some evidence to support this contention, and there is little doubt that more will emerge in due course.

Rivers in the Anglian Region of the NRA are subject to a rolling programme of fisheries surveys on a three year time scale. Consequently most rivers have not yet had post drought surveys, and nor does information on the strength of fish year classes emerge immediately. The survey methods used do not sample very small (and young) fish, which are not reliably captured until 1-3 years growth has been achieved. It is therefore probable that many influences of the drought on river fish stocks, both good and bad, remain to be detected.

7.2) Water transfer and augmentation schemes

The very large additional river flow generated by the Ely-Ouse to Essex water transfer scheme was a principal source of public concern throughout the drought. Comments, enquiries and complaints were received primarily at times of maximum transfer rates, and were made mainly by anglers. Although some concerns were expressed about the Stour, the majority of complaints were directed at the impact on the River Blackwater. Details of the operation of the transfer are given in section 5.1.

Essentially, the anglers were concerned about three things. These were:

1) The very high sustained flows generated, which were sometimes claimed to be so great as to effectively prevent angling from taking place;

2) The marked fluctuations in water levels which sometimes accompanied changes in the rate of transfer, and which usually accompanied high rate but short duration pump tests;

3) The direct impact on the fish populations themselves, including the general impact on their (river) habitat.

Complaints and enquiries received from the non angling public were mostly about the brown discolouration and other visually evident phenomena generated by algal seeding of the headwaters and transmitted downstream to all reaches. In June 1992, one complaint was incited by a temporary shutdown at Kennet pumping station, which led to the drying of Kirtling Brook. This caused some consequent smell nuisance, and allegedly impacted on the nesting success of ducks and kingfishers.

Concerns over flows were almost exclusively directed at the River Blackwater, but those in other categories were equally directed at the Stour. The issue reached a head in the early part of 1992, when the transfer scheme was operating at full capacity on a sustained basis. Anglers alleged that the last 2 months of their 1992 season on the Blackwater were effectively "washed away".

Figures 52-58 show how the Ely-Ouse flows related to both the total flows at principal gauging stations on the Stour and Blackwater, and to the percentile exceedance values for those stations, during February 1992. On the Stour upstream of Wixoe (Figure 52) the flow was almost exclusively transfer water, running consistently at the 2%ile level and generating a total flow which was even higher. Proceeding down the Upper Stour, a rapid amelioration of flow regime is apparent by Westmill (Figure 53), where the 10%ile was rarely exceeded. This is due largely to the abstraction at Wixoe for onwards transfer to the Pant/Blackwater system. In the middle reaches at Lamarsh, flows hovered around the 20%ile mark, a level which was rarely exceeded approaching the lower reaches at Langham (Figures 54-55). The Essex Water Company abstractions at Langham and Stratford St Mary, which the scheme is designed to support, ensured that flows further downstream were much more moderate.

At Copfold Hall (Figure 56), the most upstream station on the Pant/Blackwater, the flow was almost exclusively transfer water, which never dropped below the 5%ile. In the middle river at Stisted (Figure 57) flows were generally around 10%ile, but at peak periods they were substantially greater. Even at the most downstream station (Figure 58), flows were always above 20%ile, and sometimes above 10%ile levels.

The data presented are not perfect in that they do not allow for any gains to or losses from the system, and show "natural flow" simply as the difference between gauged flow and Ely-Ouse output. Nonetheless they clearly demonstrate that the impact on flows throughout the Blackwater is much greater than that on the Stour, where only the upper reaches (down to Westmill) are so severely affected. This evidently accounts for the greater frequency of complaints from the Blackwater anglers. It is also interesting to note that for the month in question, Ely-Ouse water was more than doubling the discharge of both rivers.

Generation of very high flows is only part of the problem; the other aspect of it is their consistency compared to more natural regimes. Figure 59 shows daily mean flows on the Blackwater for four separate months with similar total discharges. Two of these were natural flows only, whilst the others comprised of high volume transfers during February and March 1992. The "natural" months show very high peaks on a few days only, with much lower flows at other times. The former represent periods of flood. By contrast, "transfer" months show much more uniform levels, which are

3.6 River Support Schemes

3.6.1 Waveney Groundwater Scheme

(Refer to map No *)

One river support scheme is licensed and operational in the Catchment: the Waveney Groundwater Scheme.

The scheme consists of 5 boreholes sunk into the Chalk and Crag aquifers situated in North Suffolk in the catchment of the River Dove; the Waveney's main tributary. The scheme was licensed in 1990 to support the River Waveney at times of low flow and to meet predicted demands for public water supply and spray irrigation from the river downstream. The most significant abstraction relying on the scheme is that by Suffolk Water Company at Shipmeadow which supplies water for public consumption to the Lowestoft area. Abstraction rates at Shipmeadow are controlled by minimum flow requirements in the river measured at Ellingham Mill Gauging Station, these are set to satisfy a minimum flow requirement further downstream of 23 thousand cubic metres per day at Burgh St Peter to control tidal salt water invasion of the river system.

The scheme is designed for intermittent use essentially during the summer months when river flows are lowest. It is licensed to discharge a total 43 and 5950 thousand cubic metres per day and year respectively into the river system to support flows in the Waveney. Not all of this quantity is available for subsequent re-abstraction due to associated natural losses, however, the system is capable of reliably increasing river flows by 28 thousand cubic metres per day, sufficient to satisfy predicted demands into the next century.

Groundwater resources currently exist in the Dove catchment to support further enhancements of the scheme, however, this would be subject to sensitive development having particular regard to existing water users and the environment.

F.A.O. HUGH GOLDSMITH

NATIONAL RIVERS AUTHORITY: ANGLIAN REGION

PERCEIVED / MEASURED IMPACTS OF TRANSFER SCHEMES

The attached list summarises obvious perceived / alleged impacts: beware many have not been critically substantiated.

See also attached note (extract from a drought impact report, this section deals with impact of Ely Ouse - Essex Scheme).

Geomorphology

Upper reaches have been "improved" to cope with transfer rates; some local erosion particularly around outside of bends and in parts of river bed (no erosion evident in lower reaches?).

TWA Scheme transfers potentially silt laden water from tidal reaches of Trent to Torksey canal (BWB) who receive payment for dredging (although little evidence that it actually occurs?).

Hay field flooded when high rate transfers started suddenly at a time of significant weed growth (& hence reduced channel capacity).

Other Physical Impacts

Periods of sustained uniform un-natural high flows

Periods of rapidly variable flow (particularly during pump testing)

Both accompanied by corresponding levels.

Repair & maintenance of bridges gates etc cannot be carried out during the summer as normal because of unusually high flows.

Operation of gates and sluices:
- can automatic gates cope; do they react correctly
- unpredictable flow times (particularly on heavily managed rivers); are gates always set correctly?
- riparian owners often react erratically and inappropriately to changing flows / levels
- NRA effort on adjusting gates under our control

Caught out at least once by pumping at high rates during unforecasted heavy rain (minor local problems)

Beware i) river management practice often assumes transfer water will always

be available - in practice pumps fail etc...
ii) when transferring from a river which itself is supported there will be time you get your sums wrong: results in falling flows / levels, saline intrusion etc...

Water Quality

Major impact can be transfer of algal rich water to low algae river & consequent changes.

Relatively rapid changes in chemistry and / or temperature particularly if augmented at different times with both ground and surface water.

Many quality impacts as might be predicted.

. Nutrient rich water into nutrient poor river.

One incident during 70's of transferring trace contaminant which killed irrigated tomato crop.

Some MAFF concern about possibility of transferring sugar beet rhizomania (particularly if donor river contains washing from beet factory): unresolved. Similar concerns at one stage about potato eelworm (?).

Concern about transferring pollution: automatic quality monitors?

Water trapped in system when no transfers: oxygen sag, anaerobic conditions, what do you do with it when you start pumping.

Discharge consents: do you set them assuming transferred water is available: what happens if you do and it isn't.

Local problems from groundwater augmentation boreholes: one abandoned due to iron content (ochre), another slightly high in sulphide which has sterilised discharge ditch (fortunately a field drain which is usually dry).

Navigation / Recreation / Amenity

See physical impacts.

High velocities a potential navigation problem, little impact in reality?

Beware sudden flow fluctuations can wash away children.

Smell if transfer switched off during hot weather.

Aquatic Ecology

Macrophyte scour in upper reaches of supported rivers.

Anything which affects macrophytes (scour, turbidity etc) affects entire ecosystem.

Seeding of rivers by algae, fluctuating clear / turbid water conditions hence changes to light intensity and macrophyte growth.

Conservation / Terrestrial Ecology

Switching off transfers alleged to impact on bird nesting success.

Fisheries

High sustained flows affect angling.

High rates of pumping can affect spawning (eg pumping at high rates from March to June coincided with cyprinid spawning season).

Clear / turbid conditions affect fish behaviour and angling.

Fish attracted into supported tributaries (particularly borehole support) left stranded when switched off.

Transfer of alien eggs / larvae / fry etc (eg zander?).

Other Comment

Transfer and augmentation scheme tend to work only during dry periods hence with / without hydrology concepts fairly meaningless.

Don't lose sight of opportunities arising from transfer works eg to flush pollution, flush blanket weed during dry periods, controlled releases for canoeing.

C. J. Thomas 17/6/93

or by upstream migration is likely to have taken place as flows returned. No major mortalities are known to have occurred on rivers as a consequence of the drought.

What is not clear from the Tables is the longer term implications for river fish stocks. In some cases, for example the River Burn in Norfolk (section 3.3), survey work has already shown that the populations have been significantly affected. Both salmonid and cyprinid stocks appeared to be largely extinct, leaving eels as the dominant species. Recovery from this position will be inhibited by the lack of breeding stock, and it is probable that artificial restocking will be required to restore the fishery once flows have returned to normal. Similar circumstances (and prognostications) may well apply to the Lothingland Hundred River in Suffolk, which was affected by saline incursion as well as low flows worsened by licenced abstractions. On the Upper River Colne the loss of fish stocks under weed cover was concentrated between Mill structures which probably impede fish movements and hence recolonization. Once again, this could delay or prevent any natural recovery.

On a more positive note, very strong year classes of several species of fish were found after the drought years of 1975 and 1976. Some of these fish are still in evidence today. The low flows and high temperatures prevalent at the time were obviously very favourable to fry survival and growth, a factor which represented a considerable boost to the fish stocks of the late 1970's. It appears highly likely that 1989 and 1990 would have been similarly favourable, on account of their excellent summers. There is already some evidence to support this contention, and there is little doubt that more will emerge in due course.

Rivers in the Anglian Region of the NRA are subject to a rolling programme of fisheries surveys on a three year time scale. Consequently most rivers have not yet had post drought surveys, and nor does information on the strength of fish year classes emerge immediately. The survey methods used do not sample very small (and young) fish, which are not reliably captured until 1-3 years growth has been achieved. It is therefore probable that many influences of the drought on river fish stocks, both good and bad, remain to be detected.

7.2) <u>Water transfer and augmentation schemes</u>

The very large additional river flow generated by the Ely-Ouse to Essex water transfer scheme was a principal source of public concern throughout the drought. Comments, enquiries and complaints were received primarily at times of maximum transfer rates, and were made mainly by anglers. Although some concerns were expressed about the Stour, the majority of complaints were directed at the impact on the River Blackwater. Details of the operation of the transfer are given in section 5.1.

Essentially, the anglers were concerned about three things. These were:

1) The very high sustained flows generated, which were sometimes claimed to be so great as to effectively prevent angling from taking place;

2) The marked fluctuations in water levels which sometimes accompanied changes in the rate of transfer, and which usually accompanied high rate but short duration pump tests;

3) The direct impact on the fish populations themselves, including the general impact on their (river) habitat.

Complaints and enquiries received from the non angling public were mostly about the brown discolouration and other visually evident phenomena generated by algal seeding of the headwaters and transmitted downstream to all reaches. In June 1992, one complaint was incited by a temporary shutdown at Kennet pumping station, which led to the drying of Kirtling Brook. This caused some consequent smell nuisance, and allegedly impacted on the nesting success of ducks and kingfishers.

Concerns over flows were almost exclusively directed at the River Blackwater, but those in other categories were equally directed at the Stour. The issue reached a head in the early part of 1992, when the transfer scheme was operating at full capacity on a sustained basis. Anglers alleged that the last 2 months of their 1992 season on the Blackwater were effectively "washed away".

Figures 52-58 show how the Ely-Ouse flows related to both the total flows at principal gauging stations on the Stour and Blackwater, and to the percentile exceedance values for those stations, during February 1992. On the Stour upstream of Wixoe (Figure 52) the flow was almost exclusively transfer water, running consistently at the 2%ile level and generating a total flow which was even higher. Proceeding down the Upper Stour, a rapid amelioration of flow regime is apparent by Westmill (Figure 53), where the 10%ile was rarely exceeded. This is due largely to the abstraction at Wixoe for onwards transfer to the Pant/Blackwater system. In the middle reaches at Lamarsh, flows hovered around the 20%ile mark, a level which was rarely exceeded approaching the lower reaches at Langham (Figures 54-55). The Essex Water Company abstractions at Langham and Stratford St Mary, which the scheme is designed to support, ensured that flows further downstream were much more moderate.

At Copfold Hall (Figure 56), the most upstream station on the Pant/Blackwater, the flow was almost exclusively transfer water, which never dropped below the 5%ile. In the middle river at Stisted (Figure 57) flows were generally around 10%ile, but at peak periods they were substantially greater. Even at the most downstream station (Figure 58), flows were always above 20%ile, and sometimes above 10%ile levels.

The data presented are not perfect in that they do not allow for any gains to or losses from the system, and show "natural flow" simply as the difference between gauged flow and Ely-Ouse output. Nonetheless they clearly demonstrate that the impact on flows throughout the Blackwater is much greater than that on the Stour, where only the upper reaches (down to Westmill) are so severely affected. This evidently accounts for the greater frequency of complaints from the Blackwater anglers. It is also interesting to note that for the month in question, Ely-Ouse water was more than doubling the discharge of both rivers.

Generation of very high flows is only part of the problem; the other aspect of it is their consistency compared to more natural regimes. Figure 59 shows daily mean flows on the Blackwater for four separate months with similar total discharges. Two of these were natural flows only, whilst the others comprised of high volume transfers during February and March 1992. The "natural" months show very high peaks on a few days only, with much lower flows at other times. The former represent periods of flood. By contrast, "transfer" months show much more uniform levels, which are generally above those of the non flood natural periods. In "natural" months, it is therefore probable that reasonable angling conditions were experienced for at least some of the time, which may not have been true at all in the "transfer months". Consequently, the pattern of angiers' complaints is quite compatible with the flow regimes experienced.

Given the scale at which transfers can occur, it is inevitable that river control structures have to be adjusted to cater for marked changes in rate. Many of these structures are old mill works, which have to be adjusted manually. There is clearly an imperative to ensure that control works do not restrict transfer flows, and lead to consequential upstream flooding. The problem of manual adjustment, and the resources required to accomplish it, are greatest if rate changes are frequent.

Figures 60-61 illustrate how flows in the Stour and Blackwater responded to rapid rate changes; both the figures commence with little if any transfer flow. Control structures were opened to coincide with the commencement of transfer, and the first recorded peaks in flow represent the release of water which results. Flows then recede again until the transfer water arrives. Figure 60 clearly shows that the second flow spikes, representing transfer water from a 24 hour pump test, arrive progressively later at the downstream stations, as would be expected. The figure also shows that the peak flow generated declines downstream; the spikes become flatter but of longer duration in the lower reaches. Two problems arise as a result. Firstly, gates throughout the river are generally set to match the pump test rate rather than the lesser flow they actually experience; secondly, the gates are open at times when flows are not continuously boosted by augmentation. The impact of both is the same; impoundment levels upstream of control structures drain down to much lower levels.

Figure 61 shows two flow spikes followed by a plateau. The first spike is gate opening, and the second the arrival of transfer water. However, the pumps were stopped again (for maintenance by contractors) after only a few hours run, before being permanently restarted about the same time later. Permanent running gave the ultimate flow plateaus. Gates were not reset to match these changes with the result that two periods of marked drain down upstream of structures were followed by a period of very high flows. This incident, and others like it, gave rise to significant levels of complaint about river regimes. Once again, the flow patterns observed are compatible with the nature of the complaint. Problems of this type are still more serious where old structures show leakage, and are not necessarily capable of retaining the head that the degree of gate opening would allow.

The difficulties described so far are concerned mainly with angling, which is inhibited or prevented by the circumstances described above. However, concerns were also expressed about the effects on the fish themselves, and on their invertebrate food resources. Apart from high flows and fluctuating levels, these revolved around the impact on habitat of increased channel erosion and loss of macrophytes, the seeding of the rivers by algae from the Ouse (causing turbid and very brown coloured water), the introduction of GOGWS or SAGS groundwater into the system (causing very clear water), the apparent fluctuations in water quality which stem from these factors, and the ability of the fish to spawn successfully in the face of peak transfer flows. (Unfortunately, the main spawning season for coarse fish runs from March to June, when transfers are frequently at a very high rate.)

All of these factors are potentially real threats to both the fish stocks and to the river environment as a whole, although there is no evidence to date to show that any quantifiable harm has occurred. The routine 3 year fishery survey programme will in due course show if any major stock changes have been precipitated, but cannot define all of the possible impacts.

Plates 1-4 (all taken in March 1993) show very clearly that the headwaters of the Pant/Blackwater have been physically affected by macrophyte loss, scouring and erosion, but there is no measure of how important this may be. Similarly, the seeding of the headwaters by algae is believed to impinge on water quality, and certainly has a visually very obvious effect. The brown and turbid water caused by algae may shade out macrophyte growths, and have far reaching consequences for the river ecosystem. To date, none of these matters have been adequately investigated, although they are the subject of a current research proposal.

A meeting was held with anglers's representatives at the North Essex District Office in July 1992, which was very helpful to both sides in achieving an understanding of the other's position. The anglers recognised the special importance of water resources under the drought conditions prevailing, whilst the NRA learnt a lot about the serious impact of poor and variable angling conditions and results on club administration, membership and financial viability. Closer liaison during major transfer periods was recognised to be potentially helpful by all parties, whilst in the long term, it was felt that there was scope for improving the operation of the scheme particularly by better control of flows and levels.

8) Impact on other freshwater biota

8.1) Biological quality of watercourses

Routine assessment of the biological quality of watercourses between 1989 and 1992 showed that a number of sites sometimes failed to reach their target standards (measured by the Lincoln Quality Index - LQI) as a result of the drought conditions. These are listed in Table XXI, which gives details of sampling dates, LQI values achieved, sampler's comments and whether or not the sample met its target standard.

In most cases, Essex catchments' sites (including the River Stour and tributaries) failed to reach their LQI targets because of low flows. Stagnant pools were formed at some locations which became silted up and discoloured by algae (Eg the River Pant 70m downstream of Great Sampford Bridge, and Bumpstead Brook at Watsoe bridge). Others became overgrown by macrophytes, with a consequent loss of habitat variety and hence fauna (Eg the Denston tributary of the River Glem at Assington Green Road Bridge, and Salary Brook at Blue Barns Farm). By the Autumn of 1990, five sites had dried out completely, with the (temporary) loss of all normal stream biota. These were the River Stour at Sipsey Bridge, Toppesfield Brook at the A604 Bridge, the Hawkedon tributary of the River Glem at Hawkedon Hall, the Mardyke East at Harrow Inn, and the West Tilbury Main Drain

TRENT WITHAM ANCHOLME SCHEME

The rapidly rising water demands in North Lincolnshire in the early 1960's, particularly those arising from the industrial expansion along the South Humber bank, caused the existing North Lindsey Water Board and the Lincolnshire River Authority to investigate schemes early in 1965 to ensure an adequate supply of water to cope with the expansion.

Various schemes were considered and the Trent–Witham–Ancholme Scheme described below was proposed as the most economic and feasible solution within the time forecast to meet the needs.

Description of Scheme

It was decided to meet the demands along the Sou Humber bank by abstracting water from the Riv Ancholme and it was therefore necessary to ensure continuous and adequate level and flow of water in t river in dry weather or summer periods. To achieve t the level of the River Ancholme is regulated by transf of water from the Lower River Witham system via pumping station at Short Ferry which pumps wa through 11 miles of 48in diameter pipeline to the Up Ancholme at Toft Newton.

In low flow periods the River Witham itself is also au mented by transfer of water from the River Trent Torksey. The water is pumped via a short pipeline to Fossdyke Navigation Canal which carries it to the Ri Witham system.

The necessary inclusion of water from the River Trent I inevitably led to caution and therefore the supply has b restricted to industrial users only.

In the first stage of the development, the River Anchol is regulated to up to a flow of 118,000 m^3/d (26 M.G.I This is made up of 59,000 m^3/d (13 M.G.D.) into pu supply for industrial uses and up to 20,500 m^3/d (M.G.D.) for increased industrial and agricultural demar particularly spray irrigation, direct from the rivers adjacent stream systems. The balance is required maintain existing demands, control of pollution, navi tion and fishery requirements.

To enable the River Witham to be augmented, sin capacities have been allowed at the Torksey Works the River Trent but have been increased to 136,000 n (30 M.G.D.) to account for river losses and incre in the demands on the River Witham.

Due to the poor quality of Trent water coinciding high tide conditions at Torksey and to satisfy object from the British Waterways Board with regard to si of the Fossdyke Canal, it was agreed in the Parliamer Act to restrict pumping at Torksey to 18 hours each leaving a period of 3 hours over each high tide fre pumping. The transferred water is therefore free of suspended solids. This has meant that the capacit Torksey has had to be set at 182,000 m^3/d (40 M.G. These quantities and abstractions are the maxima tha envisaged necessary in severe drought conditions. average quantities to be abstracted and transferred w much less.

A level recording station has been constructed or Lower River Witham at Kirkstead Bridge. This st monitors river levels in the Lower River Witham from w pump control at Torksey is derived. A similar level cc station has been constructed at Worlaby on the Ancholme just downstream of Brigg.

The works to abstract water from the River Withar located approximately half a mile up the Barlings which is a tributary of the River Witham. The retained of the River Witham backs up this section of the Ba Eau, however, an improvement was necessary bet the works and the confluence to ensure that the max quantities could be abstracted with the minimum W water level. A similar improvement was carried out widening of the River Ancholme downstream of th Newton outfall works.

The Barlings Eau at the point of abstraction is infest a colony of fresh-water mussels and to prevent infes and also slime formation in the pipeline, the water

Short Ferry is chlorinated. The chlorination equipment is housed in the ancillary building and comprises a chlorinator and residual recorder together with the ancillary equipment for dosing chlorine. The water is dechlorinated at the Toft Newton outfall works before discharging into the River Ancholme.

The outfall works at Toft Newton includes a 16·5 hectares (41 acres) embanked reservoir, with a maximum depth of water of 6 metres (20 feet) giving 761,000 m^3 (168 M.G.) storage of river water, or up to approximately seven days reserve, for emergency use in the event of failure of plant and equipment and also for use in quality control. The banks have been designed and facilities provided for trout fishing and initial stocking with rainbow and brown trout has proved successful.

Control

In considering the control of the scheme, account had to be taken of land drainage and navigational requirements together with fisheries and other amenities. These requirements have had the effect of allowing a very narrow band of water levels within which the scheme has to be controlled and operated.

Further Development

The scheme may readily be augmented and expanded to provide for further increasing industrial and agricultural demands throughout the Lincolnshire and South Humberside areas. It is anticipated that the scheme will be developed in three stages.

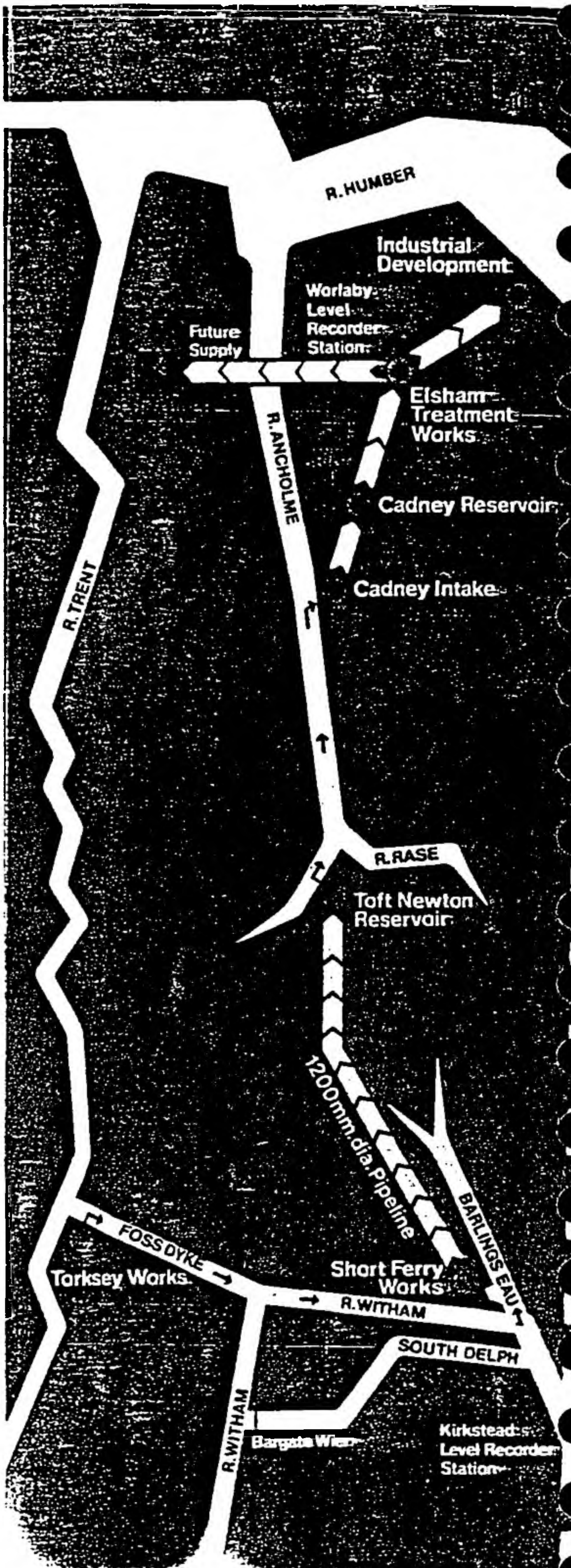
The works have been planned and constructed to allow for expansion to Stage II with regulation flows of up to 182,000 m^3/d (40 M.G.D.) in the River Ancholme. This capacity allows for an additional 59,000 m^3/d (13 M.G.D.) to be taken for public water supply and an additional 4,500 m^3/d (1 M.G.D.) for direct industrial and agricultural uses on the River Ancholme. It will only be necessary to add additional pumping plant to the pumping stations on the River Witham and the River Trent to enable these enhanced quantities to be transferred. Quality control and more efficient telemetry control facilities will likely be introduced at this stage as a result of operating experience.

Stage III of the scheme would allow for regulation of the River Ancholme up to 236,500 m^3/d (52 M.G.D.) giving an additional yield of 36,500 m^3/d (8 M.G.D.) for public water supply and 18,000 m^3/d (4 M.G.D.) for direct agricultural and industrial use. Alternative methods of producing this increased yield have not yet been evaluated.

The 1971 Act empowers the Authority to abstract up to a maximum of 91,000 m^3/d (20 M.G.D.) from the River Ancholme at Cadney Bridge, 4 km south of Brigg, though the intake works and pipeline are designed for twice this capacity to meet the ultimate requirements of the scheme.

The Fossdyke Navigation and the River Witham System from Lincoln to Bardney form a natural aqueduct to convey the water between the works at Torksey and Short Ferry.

Whereas no specific works are required in Lincoln, provision was made in the Act for the construction of aeration stations along the Fossdyke. It is anticipated that an oxygen sag point will occur at some point or points along the Canal and the location of these aeration stations will be sited after operational experience.



RIPTION OF WORKS —CONSERVATION SCHEME

ey Works

and pumping station.
0 metres of 1,370 mm diameter steel pipeline and an works, including aeration facilities.
l spindle type pumping plant suspended into a wet mp with the motor room housing both the motors and e associated control equipment above known flood There are three pumping units installed, each of HP and a capacity of 113,000 m³/d (24·8 M.G.D.)
tomatic quality monitoring and control equipment.

ort Ferry Works and Pipeline

structure, comprising dual concrete channels.
ing is performed in two stages:
i) Rough screen of horizontal bars rotating as a continuous band elevator.
andscreens having panels of 10 mm square mesh.
intake channel has the capacity to pass the full flow equired at minimum river levels.
al spindle mixed flow two-speed type pumping plant nded into wet sumps from the motor room floor, which is above known flood level. Two units are installed, each of 172–323 WHP and a maximum capacity of 0 m³/d–88,500 m³/d (12·2 M.G.D.–18·5 M.G.D.).
ipeline approximately 17½ km long comprises of a 1,290 mm outside diameter steel pipe, 10 mm thick -lined with 20 mm of granolithic concrete.
are short sleeve type internally welded with a full rength fillet weld and externally with a seal weld. The nnulus between the welds being air tested to a pressure psi.
air valves have double 100 mm valves to guard against alfunction during surge conditions.

oft Newton Outfall Works and Reservoir

city:	761,000 m³ (168 M.G.)
A	Approximately 16½ hectares
Maximum depth:	6 metres
op water level:	14·6 metres O.D.N. (approx. 4½ metres above general ground level)

A 1,220 mm diameter inlet and a 1,220 mm diameter combined outlet overflow pipe, with draw-off tower at reservoir end housing the inlet and outlet control s. The inlet main is continued across the bed of the reservoir towards the opposite corner to aid circulation of water within the reservoir.
ll into the River Ancholme is via a reinforced concrete ture which acts as an energy dissipater, an aeration weir and a flow gauge, the flow measurement monitors utput of the works and controls discharges from the oir and the de-chlorination equipment.

DESCRIPTION OF WORKS—SUPPLY SCHEME

Cadney Intake

The intake house has coarse screens and two fine drum screens with backwashing, trash removal and chlorination equipment.
A concrete pipeline, 1,800 mm diameter, and 2 km long, conveys water to the reservoir.

Cadney Reservoir

Earth embankment, constructed of rolled Oxford clay excavated from within the reservoir area.

Capacity:	900,000 m³ = 7 days' storage
Water surface area:	14 ha.
Depth:	11 metres

Cadney Pumphouse

Two low lift pumps, each of 1,060 l/s capacity, for filling the raw water reservoir or recirculating the stored water.
Two high lift fixed pumps and two variable speed pumps for delivering water to Elsham Treatment Works at an elevation of 90 m.
The fixed speed units range from 130–300 l/s.
Standby diesel generators, surge vessel, compressors and chlorination equipment.
Transfer of raw water to Elsham is through a 1,220 mm diameter steel pipeline, 10 km long.

Elsham Treatment Works

Stage I: Four "Accentriflocs" and eight rapid filters for partial softening, sedimentation and filtration.
Stage II: The number of "Accentriflocs" and filters will be doubled.
Chemical block, machine hall with relift pumps and generators, administration block, control room and laboratory.
45,000 m³ treated water covered reservoir adjacent to works.
Emergency overflow lagoon.

Killingholme Sludge Disposal Works

15 km PVC pipeline to a disposal works at Killingholme.
Four tidal retaining tanks.
Disposal of the sludge into the Humber estuary allowed during the first 4½ hours of the ebb tide.

Operation and Control

The Supply Scheme has been designed to be automatically controlled by a PDP 8/E computer, with 32 K core store located in the control room at Elsham, with outstations at Cadney Bridge, Cadney Carrs and Killingholme, linked by VHF radio. The two outstations at Cadney and the works at Killingholme will be unmanned.

Conservation Scheme Costs

		£
1.	Torksey Pumping Station, Pipeline and Outfall Works	280,000
2.	Short Ferry Pumping Station and Pipeline	1,631,000
3.	Toft Newton Reservoir and Outfall Works	566,000
4.	Land, Compensation and Legal Costs	190,000
5.	Engineering Charges and Overheads	181,000
6.	Other Works, Supplies, Services and Fittings	152,000
		£3,000,000

Supply Scheme Costs

		£
1.	Cadney Intake, Pipeline, Reservoir and Pumphouse	1,880,000
2.	Elsham Treatment Works and Reservoir	1,650,000
3.	Raw and Treated Water Pipelines	2,850,000
4.	Sludge Outfall Works	150,000
5.	Plant	1,010,000
6.	Land, Fees, etc.	560,000
		£8,100,000

Anglian Water
LINCOLN DIVISION
Waterside House, Waterside North, Lincoln LN2 5HA

Produced by the Information Unit for the Lincoln Division.

TRENT

WITHAM

ANCHOLME

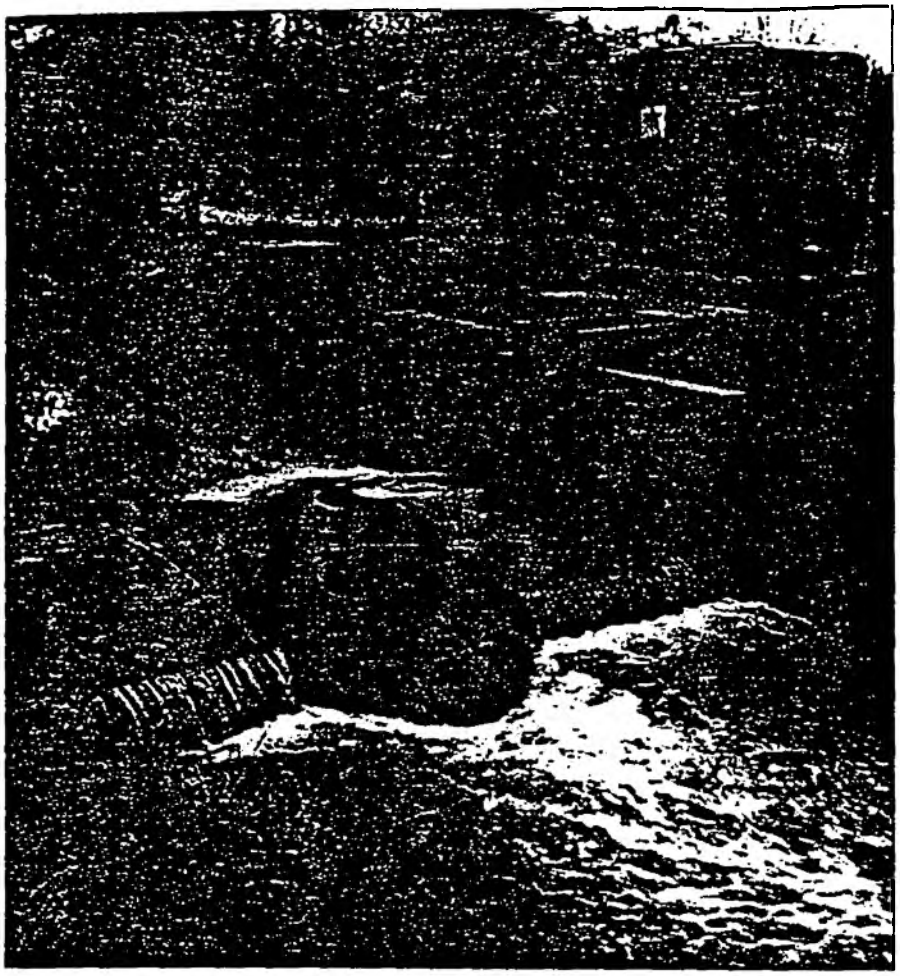
Water Conservation Scheme

Anglian Water

LODES - GRANTA GROUNDWATER SCHEME

NRA

National Rivers Authority
Anglian Region



The Lodes-Granta Goundwater Scheme is designed to improve the water environment to the north and east of Cambridge and at the same time provide more water to meet increasing public demand in a rapidly expanding part of the country.

INTRODUCTION

Towns and villages in this part of Cambridgeshire get their water supplies from the chalk which outcrops in the eastern part of the basin of the River Great Ouse. In spite of the predominantly agricultural nature of the area it has seen substantial residential and industrial development in the last 20 years and this has put pressure on existing sources of supply.

In the past it was possible to develop new borehole sources in the chalk as and when required but since the early 1970s it has been necessary to have a management plan for the area to ensure that increased abstraction does not have an adverse effect on the aquatic environment of the river system.

This plan, known as the Great Ouse Groundwater Scheme, involves managing the chalk aquifer (a natural underground reservoir) in such a way that additional water can be taken from the chalk not only for public supply and local agricultural needs but also to preserve river flows at levels sufficient to improve river water quality and maintain local amenities. The Lodes-Granta is an extension of this scheme.

THE AREA

The area extends over more than 608 sq. km. from the River Granta, south of Cambridge, northwards towards Newmarket and the high level water courses known as the Cambridgeshire Lodes.

An area with a traditional East Anglian landscape of small villages scattered across an intensively farmed environment, it sits on a bed of chalk which provides a natural source of high quality water drawn mainly from boreholes.

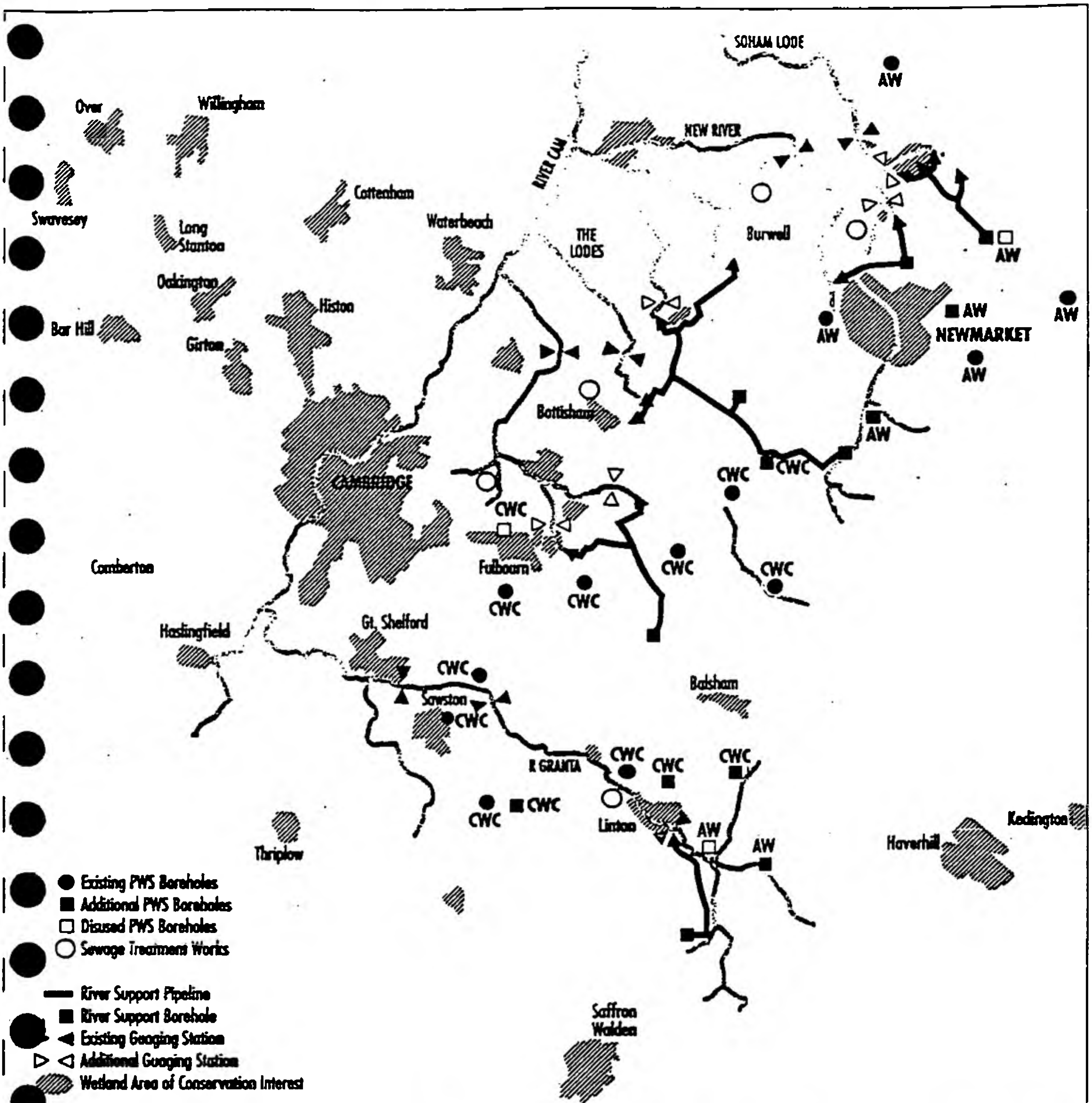
Extensive abstraction of water takes place within the district and on occasion, for example when there is low rainfall, the flows in rivers, streams and some of the Lodes can be affected. For a number of years there has been some local concern about flows in local rivers and watercourses and this has been addressed in the development of the scheme.

The area is also environmentally sensitive. In addition to the general quality of the landscape and water environment there are a large number of Sites of Special Scientific Interest including Chippenham Fen (114 hectares), Wicken Fen (247 hectares) and Fulbourn Fen (26 hectares) all in Cambridgeshire. Many of these important wetland sites rely on the careful management of the local chalk aquifers for their continued conservation.

THE SCHEME

Objectives

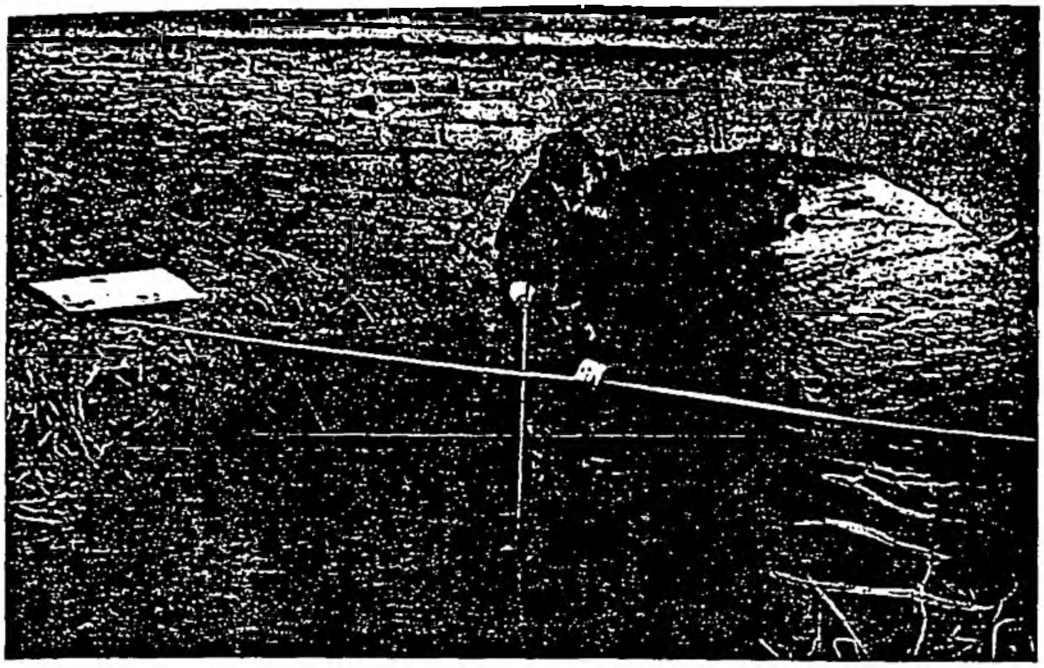
The National Rivers Authority Unit is responsible for managing, protecting and improving the water environment and this scheme is a practical example of how these objectives can be achieved:



...nagement - the scheme ensures that the ...s of the whole of the water environment ...taken into account and that a balance is maintained between the level of abstraction ...he conservation of amenities.

this extends from the p...ction of sensitive areas such as Sites of Special Scientific Interest and the river environment to the maintenance of public w... supplies.

these stem from enhanced f... in local rivers and watercourses with a consequent increase in river water quality.



allow increased abstraction by the Cambridge Water Company and Anglian Water from specified sources.

Under the scheme no additional water is being taken for public supply until the river support facilities are provided.

THE BENEFITS

The advantage the scheme are:

- river flows are improved resulting in a general enhancement of the water environment; river water quality is improved because of better flows and increased dilution;
- the environmental needs of important ecological sites (e.g. Chippenham Fen) are met and the balance of other wetland sites of special scientific interest will be maintained;
- increased abstraction for public water supply is managed in a coherent and responsible manner.

TIMESCALE

The scheme was approved in 1989 and the Granta section started in 1990 was completed two years later. The Lodes element will be completed by 1994.

INVESTIGATIONS

As part of a comprehensive review of the water needs of the area the NRA undertook an intensive investigation into the feasibility of a number of options ranging from doing nothing to developing sources of supply outside the area.

This task involved evaluating about 35 computer model simulations of what would happen with specific options and has drawn upon a wealth of data collected as a result of:

- drilling and test pumping boreholes;
- measuring flows in rivers and streams;
- mapping the geology and hydrology of the area;
- identifying wetlands and groundwater discharges.

Sophisticated methods of analysis were developed as part of the investigative programme so that detailed information could be provided to the Cambridge Water Company and Anglian Water (the main abstractors) and to conservation and environmental interests. Computer modelling work was carried out in conjunction with the Department of Civil Engineering, Birmingham University.

The end result of this exhaustive appraisal and consultation exercise was to develop a *preferred option* which centres on the *limited* development of the aquifer and extensive support for local rivers. This option will serve to balance the development of resources with conservation and environmental requirements whilst protecting the interests of existing water users.

Costing about £2.4 million this option involves developing six river support boreholes and the associated pipelines and outfalls to take the water to local streams and rivers. This will maintain river and environmental needs and

Published by Public Relations Dept., National Rivers Authority, Anglian Region, Kingfisher House, Goldhay Way, Orton Goldhay, Peterborough PE2 5ZR. Tel: (0733) 371811

PT2/4/93

Anglian Water Authority

GREAT EAU SCHEME

The demand for water in the Division's area of supply has increased dramatically since 1965 through the development of process industries on the Humber Bank. This expansion has overdrawn available ground water resources derived from boreholes sunk through the chalk formation in the vicinity of Grimsby. These resources have been augmented by the Great Eau Scheme which utilises surface water abstracted from the River Great Eau, Louth Navigation and Waithe Beck. River flows vary continually with rainfall and general climatic conditions resulting generally in high flows during the winter months and low flows during the summer and autumn. These varying flows are [illegible] Covenham reservoir which has a capacity of 2,400 million gallons and will enable a constant supply of up to 16 million gallons [illegible] pumped to consumers. In order to abstract the large quantities of water required to replenish the reservoir water levels in the Louth Navigation are regulated automatically by raising or lowering weir gates at Tetney Lock. Further weir gates together with an intake and pumping station are located on the lower reaches of the River Great Eau at [illegible] to permit the transfer of water from this river system through a [illegible] diameter pipeline to the Louth Navigation. The treatment works at Covenham enable all harmful impurities in the river water to be removed to produce a clear sparkling water which is both chemically satisfactory and bacteriologically pure. Treated water is then pumped through 12 miles of 36 inch diameter pipeline to the industrial and domestic consumers between Grimsby and Immingham. Treated water has been pumped into supply from June 1969 and the completed scheme was officially opened by Princess Alexandra on [illegible] May 1970.

COVENHAM RESERVOIR

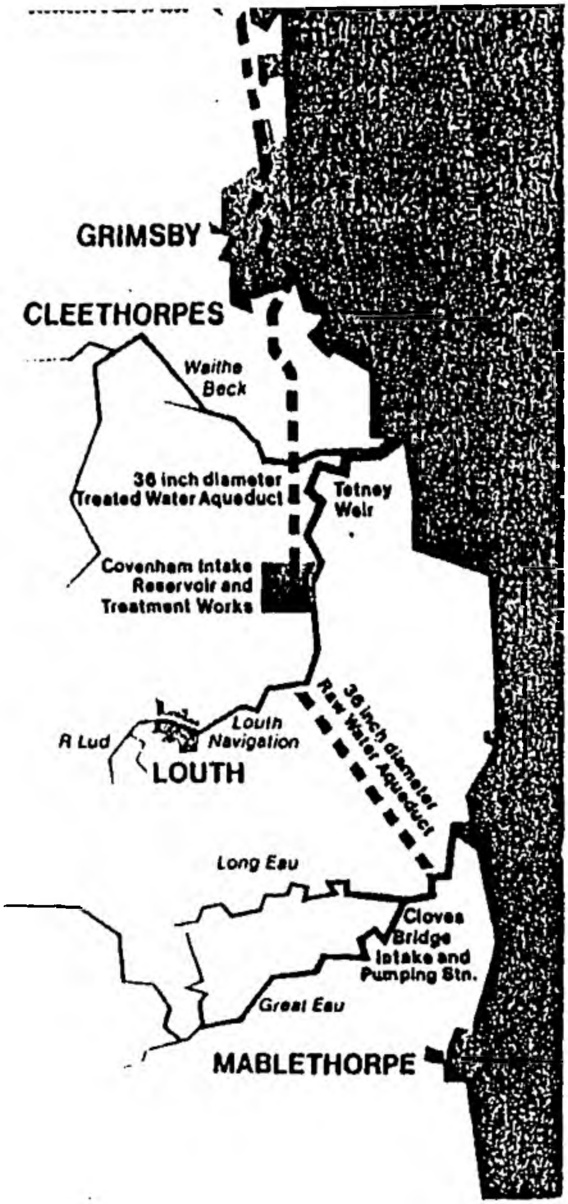
This pumped storage reservoir is located at Covenham to achieve minimum costs with the least possible interference to agriculture and local interests. These criteria dictated a water depth of about 50 feet and necessitated the reservoir being founded on boulder clay.

Discontinuous silt and sand layers occur within the foundations and these were sealed to prevent seepage of water by means of a clay cut-off. Embankments were formed over this cut-off with boulder clay excavated from within the site and placed under strictly controlled conditions to ensure an impermeable structure having adequate strength to withhold the impounded water. Sand blankets, placed over the foundations and at regular vertical intervals up both faces, allow for release of internal water pressure within the banks. Stone beaching and concrete slabbing have been laid on the internal bank faces and a wave wall provided along the crest as protection against wave action. The external faces are grassed to prevent surface erosion by heavy rainfall.

The main structure within the reservoir is the draw-off tower, which contains pipework and controls to enable water to be impounded and released simultaneously. Jets at the end of the inlet pipework give the water an anti-clockwise motion and a remote draw-off point has been provided in the centre of the reservoir. These devices are designed to discourage stratification and keep the large mass of water in circulation. As well as balancing variable river flows, storage of water in a large reservoir has the beneficial effect of improving quality and making treatment easier.

Dinghy sailing, water skiing and other aquatic sports are permitted on the reservoir and the Lincolnshire County Council have a schools sailing centre established in the village.

Capacity	2,400 million gallons
Water surface area	218 acres
Maximum water depth	46 feet
Length of embankments	2.3 miles



GRIMSBY
CLEETHORPES
Waithe Beck
36 inch diameter Treated Water Aqueduct
Tetney Weir
Covenham Intake Reservoir and Treatment Works
36 inch diameter Raw Water Aqueduct
Louth Navigation
R Lud
LOUTH
Long Eau
Cloves Bridge Intake and Pumping Stn.
Great Eau
MABLETHORPE

TREATMENT WORKS

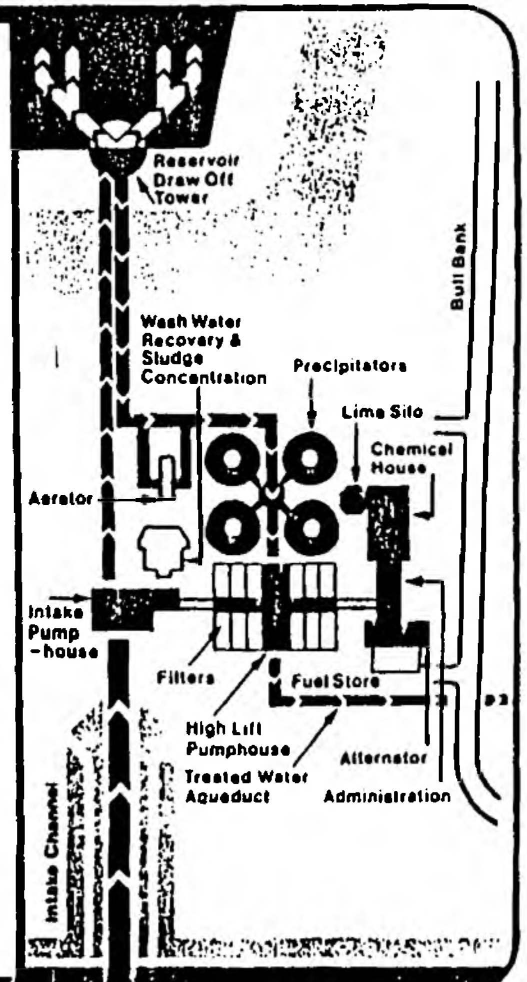
Raw water abstracted from the intake canal passes through coarse screens to prevent floating debris and large suspended matter being pumped into the reservoir. After storage, water is screened to remove fish and if required, aerated, after receiving an initial dose of chlorine to oxydise organic matter present. Lime and chlorinated copperas are then added as the water passes to four large circular tanks known as "Precipitators". It is here that both softening and removal of most of the impurities takes place by a process of coagulation, flocculation, and settlement.

Further chemicals can be added as water leaves these tanks, to ensure that it is neither acidic or excessively alkaline and to improve its taste. Next, water is fed into the rapid gravity filters which consist essentially of rectangular tanks containing graded sand and pebbles beneath a layer of specially prepared anthracite. The filtered water finally passes to a contact tank where it is given a further dose of chlorine to ensure complete disinfection. The treated water is then pumped to consumers by four 400 H.P. variable duty pumps.

All chemicals used in the treatment process are delivered and stored in bulk. From these, chemical solutions are prepared and the requisite quantities injected by metering pumps capable of adjustment in proportion to the quantity and quality of water being treated.

Electrical power is received under normal conditions from the Yorkshire Electricity Board at 11kV. On failure of this supply, 1250 H.P. diesel alternators automatically come into operation. This plant is designed to operate with attendance only during normal working hours. The automatic control system operates alarms when the processes or flows deviate from predetermined values. The staff at the works consist of a works superintendent, a works foreman, 4 plant operators, 3 labourers, 1 reservoir warden and the works also house an Area chemist and 2 laboratory assistants who monitor the Great Eau scheme raw water sources including Covenham reservoir and control the quality of water leaving the works, and in addition carry out routine chemical and bacteriological examinations of all raw and treated water sources in the Eastern Area of the Lincoln Water division. The planned maintenance and emergency repair of the electrical, electronic, hydraulic and mechanical equipment is undertaken by the maintenance staff from Grimsby.

Above left: Precipitators. Above right: High lift pumps.



GREAT OUSE GROUNDWATER SCHEME

GOGWS

THE BACKGROUND

The River Great Ouse and its tributaries have long been a source of water both for public supply and industrial use. The river flows into the Wash and drains an area of 3,314 square miles. Supplies of water from the chalk which outcrops in the eastern part of the Great Ouse basin, have from time immemorial met the water needs of the villages and towns of an area in which agriculture is still the main industry.

The water abstracted from the natural aquifer (underground reservoirs) of the chalk amounts to about half of all the water used in East Anglia. It used to be possible for the water supply authorities to develop new borehole sources in the chalk as and when required, without in the main interfering seriously either with existing sources or with the summer flows and water quality of the rivers, but the development of the additional supplies of water now needed for an increasing population and industrial expansion in East Anglia must be carefully and comprehensively planned so as to avoid any adverse effect on the amenities of the river system and on existing sources of supply.

THE FUTURE

In view of the successful completion of the pilot scheme, th Authority has decided to apply for the necessary statutory Order ui the Water Act 1948 (including where necessary compulsory purcl the reasons why these are necessary are explained on the sep annexed). Powers are being sought to authorise groundwater ab area of about 100 square miles in the catchments of the Rivers Little in Norfolk and Suffolk, and in an area of about 70 square miles in t areas of the Rivers Cam and Rhee in Cambridgeshire and Hertfordsh of 170 square miles is the first stage of the development and extent Norfolk down to North Hertfordshire. Although the proposals are part of meeting future demands for water in South-East England, priority will meeting demands from consumers within the Great Ouse basin.

This first stage will entail the construction of a network of 69 abstr sites (i.e. 52 new sites and the 17 sites already constructed under the ex scheme) to be used for water supplies and the maintenance and improv river and stream flows. One hundred and fifty observation boreholes will b to provide continuous information about groundwater levels, and about 8C pipeline. A proportion of the water taken for public water supply will be ret the rivers in the form of treated sewage effluent. One of the 18 wells alrea structed under the experimental scheme has been transferred to the Water Division for local use and is therefore not included in the scheme.

The abstraction well sites are spaced throughout the areas covered by stag of the scheme and there could be more than one well at any one site. The wel be built gradually as may be most appropriate to meet future requirements.

27 BOREHOLES CONSTRUCTED GIVING 130 Mld GROSS OUTPUT, 69 Mld NET AT ABSTRACTION POINT

Throughout the period 1972–74 the Authority and its predecessors cons with landowners, farmers and others regarding the location of the well sites which powers are sought. There has been very extensive consultation with lc authorities, conservation, angling and other interests, the National Farmers' Un and the Country Landowners' Association.

Both the N.F.U. and C.L.A. have shown general support to the Scheme as beir preferable to the construction of surface reservoirs. The first stage will take abou four years to complete, but by the end of this century, if powers are granted tc extend the Scheme over 960 square miles of potential development, a network ol about 340 sites will by then have been established in order to provide a vital supplementary source of water to help keep pace with the Region's growing demand.

THE PILOT SCHEME

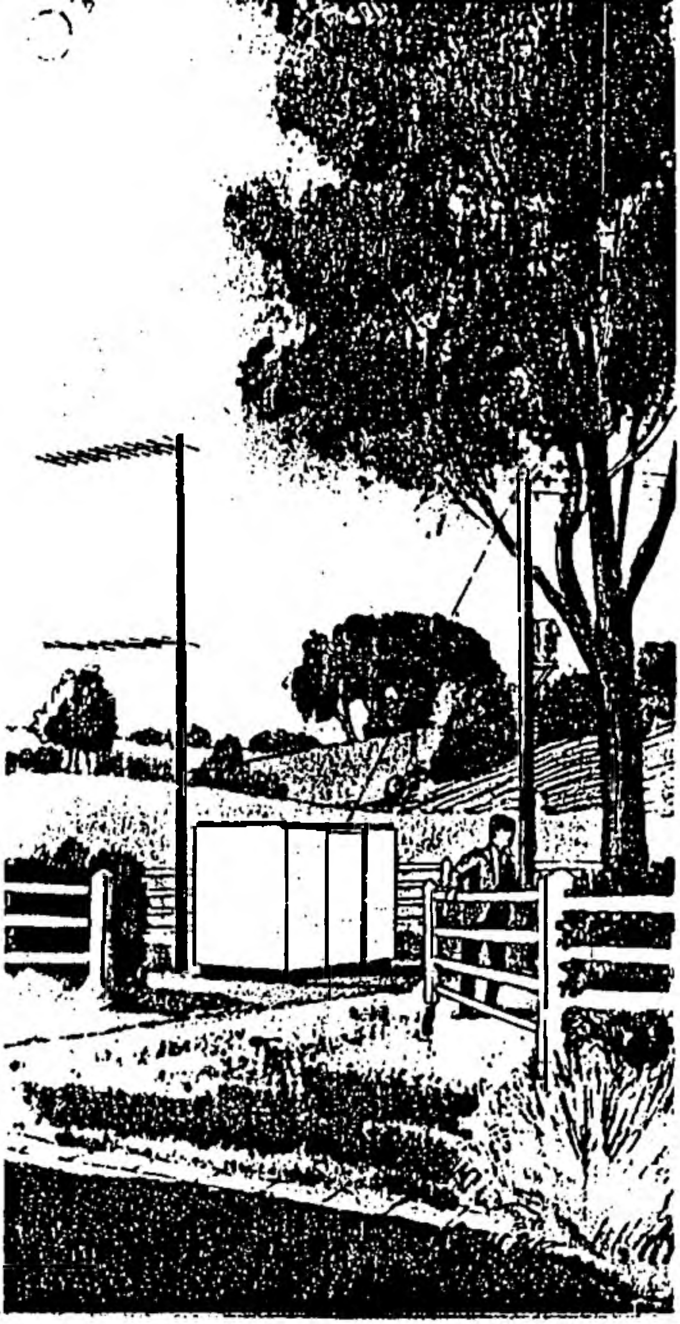
The former Great Ouse River Authority, having accepted the Water Resources Board's recommendations, carried out a pilot investigation using the River Thet in an area of 28 square miles around East Harling, near Thetford in Norfolk. A control area was established in the adjacent River Wissey catchment so that comparisons could be made between groundwater levels and river flows in the pilot area and those in the control area where no abstraction was taking place.

The investigation comprised two stages, the first of which was the establishment of a network of river flow gauges, rain gauges, groundwater level observation boreholes and other equipment needed for the accurate measurement of effects in both the pilot and control areas. The second stage, which began in 1968, was the construction of 18 abstraction wells, the installation of pumping plant, the construction of discharge pipelines and stream outfalls, and the improvement of local watercourses. In the spring of 1969 the first experimental pumping was carried out from 10 wells adjacent to the River Thet and its principal tributaries, and by 1970 the programme had extended to the continuous use of all the 18 abstraction wells at their maximum rate of output. Pumping from these wells continued until October 1970 at an average of 15½ million gallons a day, and the pumps were then gradually closed down in a pre-determined sequence so that further observations could be made. The final test was to simulate the use of the system under operational conditions, and the number of wells in use at any one time was decided on a daily basis dependent upon the weather forecast, soil moisture deficits and actual river flow.

It has now been proved that it is possible to increase natural river flows by pumping groundwater into the rivers and that the groundwater levels, although depressed by the pumping of the stored groundwater will quickly recover.

At the same time as the engineering and hydrological investigations took place, effects on the environment were being studied. Except as stated below the pumping had no adverse effects on stability of buildings, on soil moisture, on the growth of crops and trees or on the environment as a whole including fish life and river quality throughout the 3–4 year experimental period, even though drought conditions were experienced in 1970 when all wells were pumped at maximum output for a period of some 261 days. The only exception was that in the case of small marginal areas of agricultural land in the close vicinity of the river, the lowering of the water table, which was previously near to the surface, did have a marginal impact on the growth of crops.

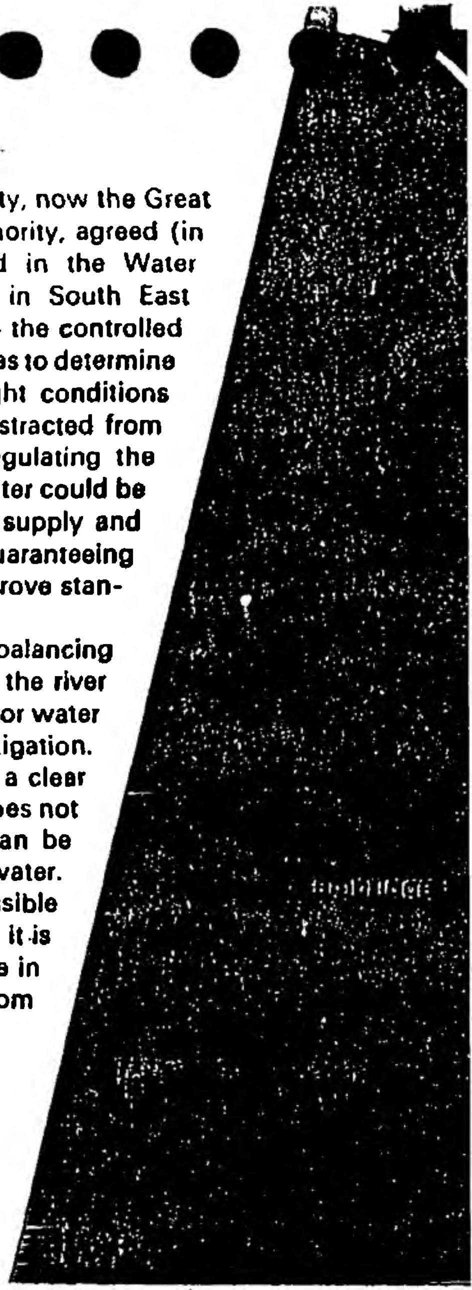
A typical abstraction well access and headworks

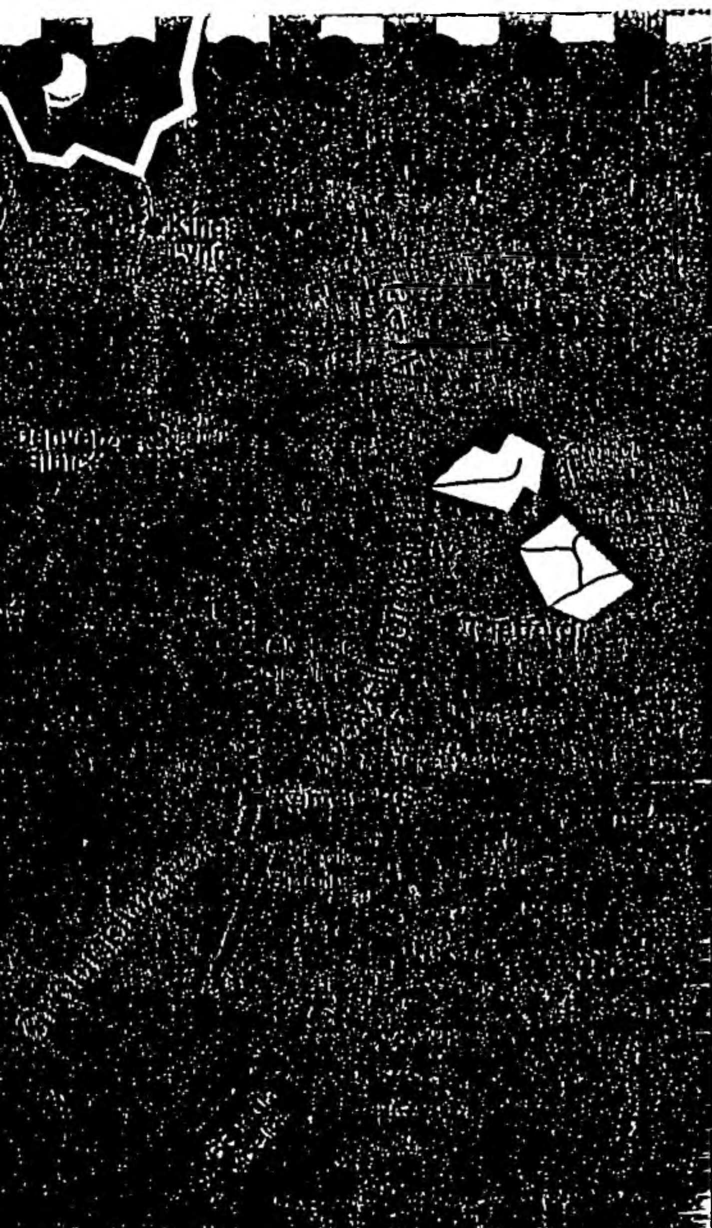


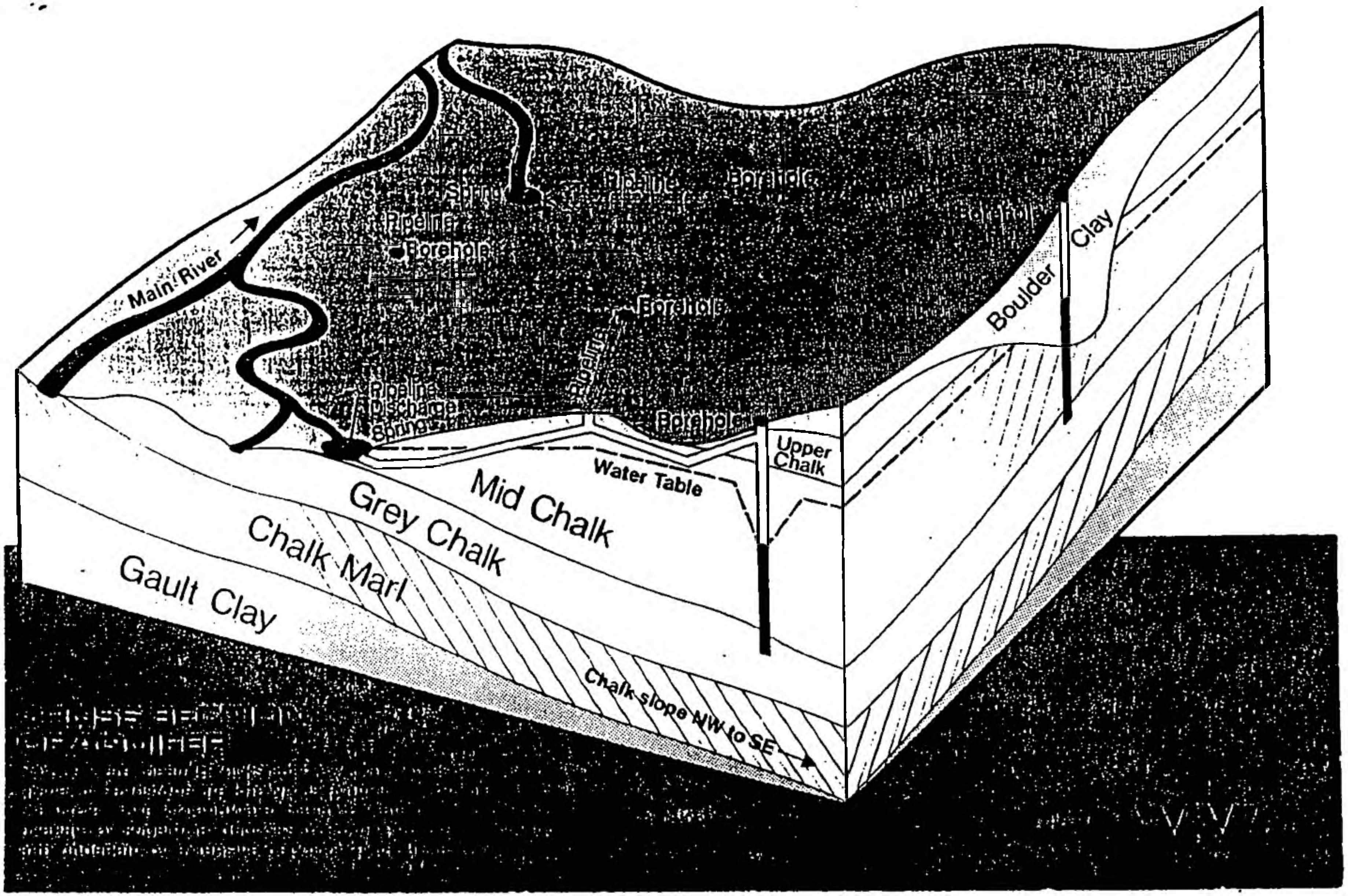
THE PLAN

During 1966 the then Great Ouse River Authority, now the Great Ouse River Division of the Anglian Water Authority, agreed (in accordance with recommendations contained in the Water Resources Board's report on water supplies in South East England), to carry out a pilot investigation into the controlled development of the groundwater in the chalk so as to determine what reliable increase of river flows in drought conditions could be achieved when groundwater was abstracted from boreholes and pumped into the rivers. By regulating the flow of rivers it was expected that additional water could be abstracted from the chalk not only for public supply and local agricultural requirements, but also for guaranteeing minimum river flows so as to maintain and improve standards of water quality and local amenity.

The new idea of using the chalk aquifer as a balancing tank from which to draw water to supplement the river in periods when rainfall is low but the demand for water is high, has required careful and extensive investigation. The use of natural underground resources has a clear advantage over a reservoir scheme because it does not involve the loss of agricultural land, and it can be developed by stages to meet rising demands for water. Also the rivers themselves will as far as possible be used to convey the water to the place where it is required, and as pumping will mainly take place in the summer, such rivers will be safeguarded from the adverse effects of a summer drought.






Main River
Spring
Pipeline
Borehole
Borehole
Pipeline
Borehole
Pipeline
Discharge
Spring
Borehole
Boulder
Clay
Upper
Chalk
Water Table
Mid Chalk
Grey Chalk
Chalk Marl
Gault Clay
Chalk slope NW to SE

SUMMARY SHEET

West Berkshire Groundwater Scheme

Objectives of the Scheme

The West Berkshire Groundwater Scheme was promoted in the early 1970's by the then Thames Conservancy with the prime purpose of augmenting river flow in the Kennet and Thames to support abstractions in London. The scheme was one part of a five phase programme; the latter phases of which were never promoted because of hydrogeological unsuitability. An operating agreement made under Schedule 2 to the Water Act 1989 states that the Scheme shall be used only under drought conditions, in emergencies and for environmental protection.

Physical Components of the Scheme

The scheme which is spread over nearly 4000 square kilometres consists of 32 boreholes and pumping stations grouped into 7 wellfields joined by 89km of pipeline to 4 major and 23 minor outfalls on various rivers and streams in West Berkshire (see map). The boreholes in wellfields 1 to 5 are drilled into the unconfined chalk aquifer of the Berkshire Downs whilst those in the wellfields 6 and 7 abstract anaerobic water from the confined aquifer and so provision has been made for aerating the water before discharge to the adjacent watercourse. Although installed pump capacity is almost 200 Ml/d it is accepted that the maximum reliable yield is only about 130 Ml/d and that this reduces to about 85 Ml/d after prolonged pumping.

Hydrology

Flow statistics (in Ml/d) for the four receiving rivers are:

River Site	Mean Flow	Minimum Annual Flow	Minimum Daily Flow	Q95	Typical Augment'n
Pang (Pangbourne)	50	16	10	18	21
Lambourn (Shaw)	140	66	42	67	38
Kennet (Theale)	810	300	120	330	52
Thames (Windsor)	4860	2870	1320	1360	85

Date of Implementation and Frequency of Operation

The scheme was constructed and commissioned in 1973-1976 and first used in full for 3 months at the end of the 1976 drought, this being the longest period of full operation for its prime purpose. The scheme was also used during the drought of 1989 for 3 weeks, with individual boreholes or wellfields being used on various other occasions to support local public water supply during times of emergency. The most regular use for one of the sites has been (and will continue to be) the seasonal augmentation of the Letcombe Brook which was identified in 1989 as one of the national "Top 20" rivers suffering unacceptable low flows due to excessive abstraction.

Perceived/Measured Impacts

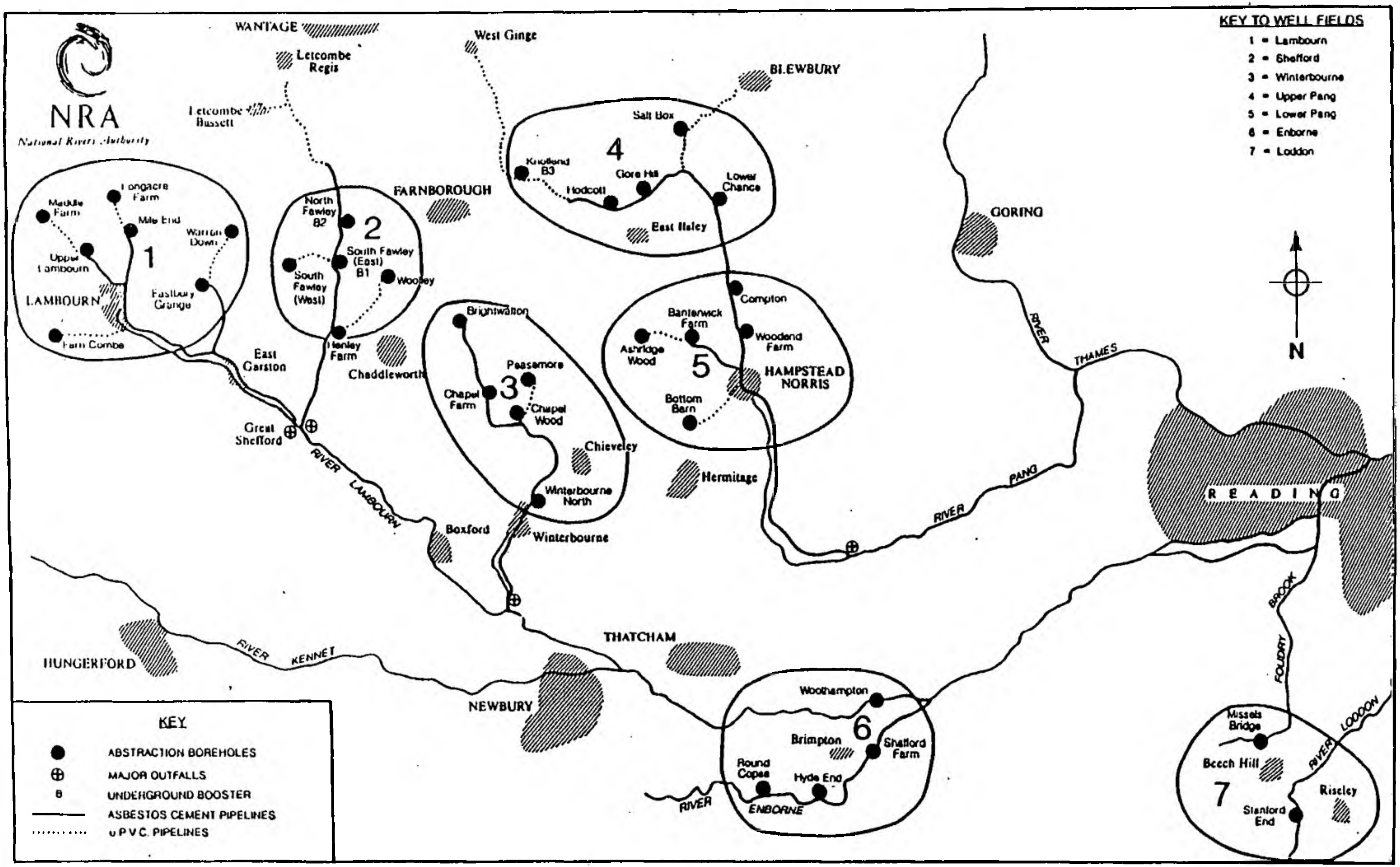
- **Geomorphology (siltation; erosion; dredging)** - whilst there has been no attempt to measure any impact, none has been perceived. The major outfalls were designed with a toothed baffle wall across the mouth of the discharge pipe followed by a shallow stilling pool and overflow sill. It has not been necessary to construct stream bed or bank protection works.

- **Other Physical Impacts (flooding; land drainage; water resources)** - The risk of flooding in the small rivers due to heavy summer thunderstorms occurring during times of augmentation was considered and a remote control facility was incorporated to allow emergency shutdown : this has to date not been used.In wellfields 1 to 5, boreholes are positioned in dry valleys above intermittent flowing bourne stream and springs and would normally operate in a drought when the springs and streams would be naturally dry. It is policy not to operate these boreholes during normal weather periods as they would derogate the local streams and springs.

- **Water Quality** - Regular sampling and analysis has shown that the Chalk water discharged to the rivers is both chemically and bacteriologically satisfactory, although as stated previously water drawn from the confined aquifer is aerated prior to discharge.

- **Navigation/Recreation/Amenity** - There are no navigational or recreational impacts resulting from the scheme. There may be a marginal amenity impact arising from the enhanced low flows through some rural communities.

- **Aquatic Ecology/Conservation/Terrestrial Ecology/Fisheries** - Although biological monitoring, river corridor and fisheries surveys have been undertaken, no impact from the scheme has been measured and quantified. There is however perceived beneficial effect on fish populations and fauna of the receiving watercourses. Any potentially deleterious impact of summer augmentation on the ecology of winterbournes, has been avoided by siting the major outfalls below the perennial head of the receiving watercourses.



WEST BERKSHIRE GROUNDWATER SCHEME

NATIONAL WATER RESOURCES STRATEGY
ENVIRONMENTAL ASSESSMENT

UPPER WYLYE RIVER REGULATION SCHEME SUMMARY SHEET

SCHEMATIC MAP	*ENCLOSED*
OBJECTIVE	*TO COMPENSATE THE EFFECT ON RIVER FLOW FROM THE GROUNDWATER PUBLIC WATER SUPPLY SCHEME*
IMPLEMENTATION DATE	*BRIXTON DEVERILL LICENCE ISSUED 1974* *KINGSTON DEVERILL LICENCE ISSUED 1975.*
PHYSICAL COMPONENTS	*BRIXTON DEVERILL REGULATION CONSISTS OF 4 BOREHOLES & PUMPS. ALSO USED FOR PUBLIC WATER SUPPLY. ONE DISCHARGE PIPE TO WYLYE. BOREHOLES ADJACENT TO RIVER.* *KINGSTON DEVERILL REGULATION CONSISTS OF 3 BOREHOLES & PUMPS. DISCHRGE IS VIA A PIPE & SPILLWAY SOME HEIGHT ABOVE RIVER.*

FREQUENCY OF OPERATION

	BRIXTON DEVERILL	KINGSTON DEVERILL
1974	JUN–DEC	NA
1975	JUL–DEC	ALL YEAR
1976	JAN–NOV	NONE
1977	?	NONE
1978	OCT–NOV	OCT–DEC
1979	?	NONE
1980	?	NONE
1981	AUG *	AUG–DEC
1982	NONE *	JUL–NOV
1983	NONE *	SEP–DEC
1984	AUG *	JUN–NOV
1985	NONE *	JUL–DEC
1986	NONE *	AUG–NOV
1987	NONE *	JUL–NOV
1988	NONE	JUN–OCT
1989	NONE	JUL–DEC
1990	JUL–DEC	JUN–DEC
1991	JUL–NOV	JUN–DEC
1992	JUN–NOV	ALL YEAR

** SUSPECT DATA*

WITH / WITHOUT HYDROLOGY	*THIS DATA IS NOT AVAILABLE. AN INVESTIGATION OF STREAM SUPPORT EFFICIENCY IS INCLUDED IN CURRENT CONSULTANT WORK ON WYLYE.*

CONTINUED OVERLEAF.........

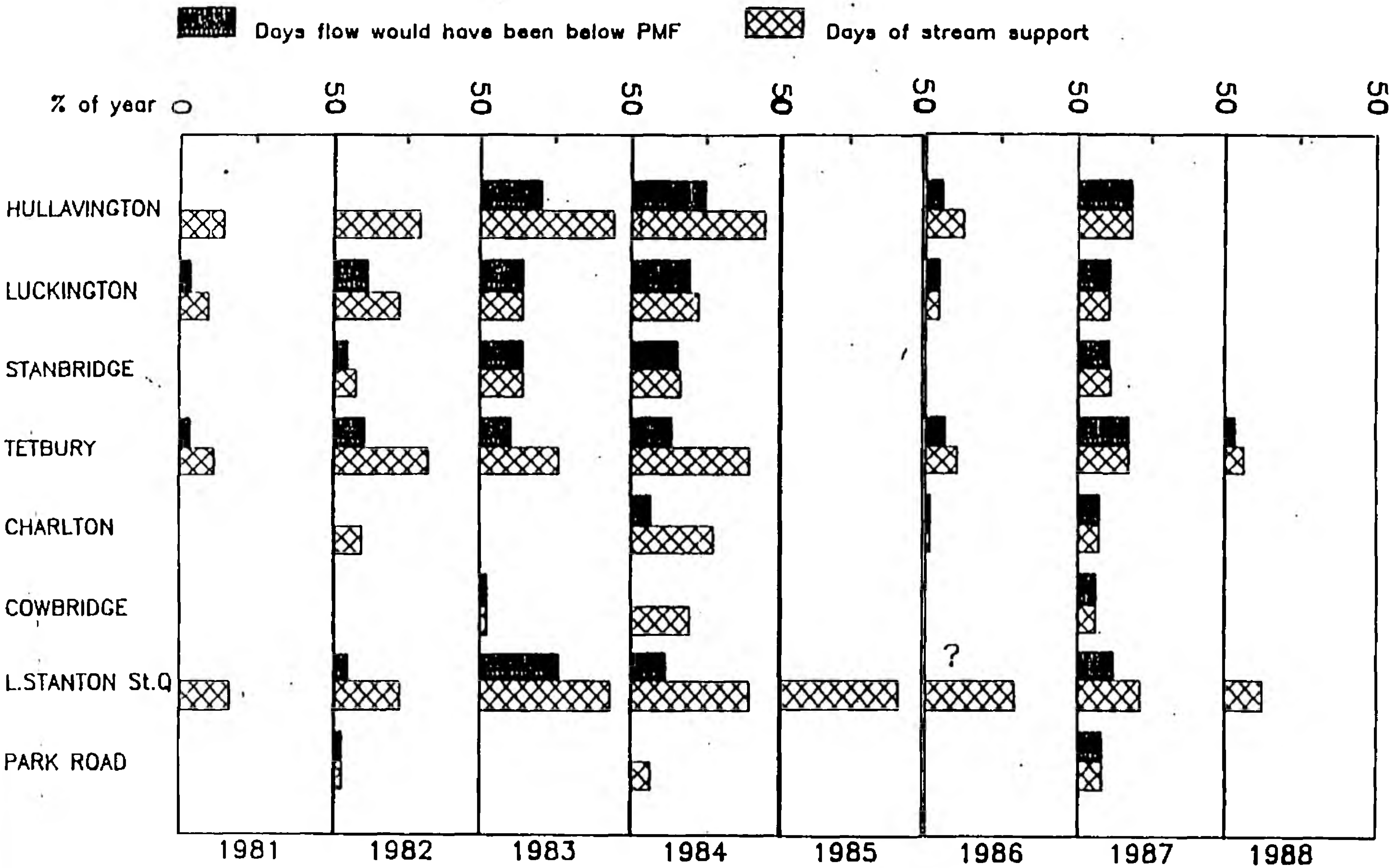
PERCEIVED / MEASURED IMPACTS

* GEOMORPHOLOGY :	NO IMPACTS
* PHYSICAL :	NO IMPACTS REPORTED.
*WATER QUALITY :	NONE – THE STREAM SUPPORT INTRODUCES LOCAL CHALKWATER TO THE RIVER (NATURAL SPRINGFLOW OF THE SAME CHALKWATER IS COMMON)
* NAVIGATION/AMENITY :	NO NAVIGATION IMPACT. AMENITY CONSOLIDATED.
* AQUATIC ECOLOGY :	ABSENT AQUATICS IN 1977 SUGGESTS STREAM SUPPORT NOT ENTIRELY EFFECTIVE.
*CONS/TERRESTIAL ECO :	NO RECORDED IMPACTS.
*FISHERIES :	FISHERIES SURVEY 1992 FOUND SIMILAR RESULTS TO 1971 – SUCCESSFUL SUPPORT CITED.

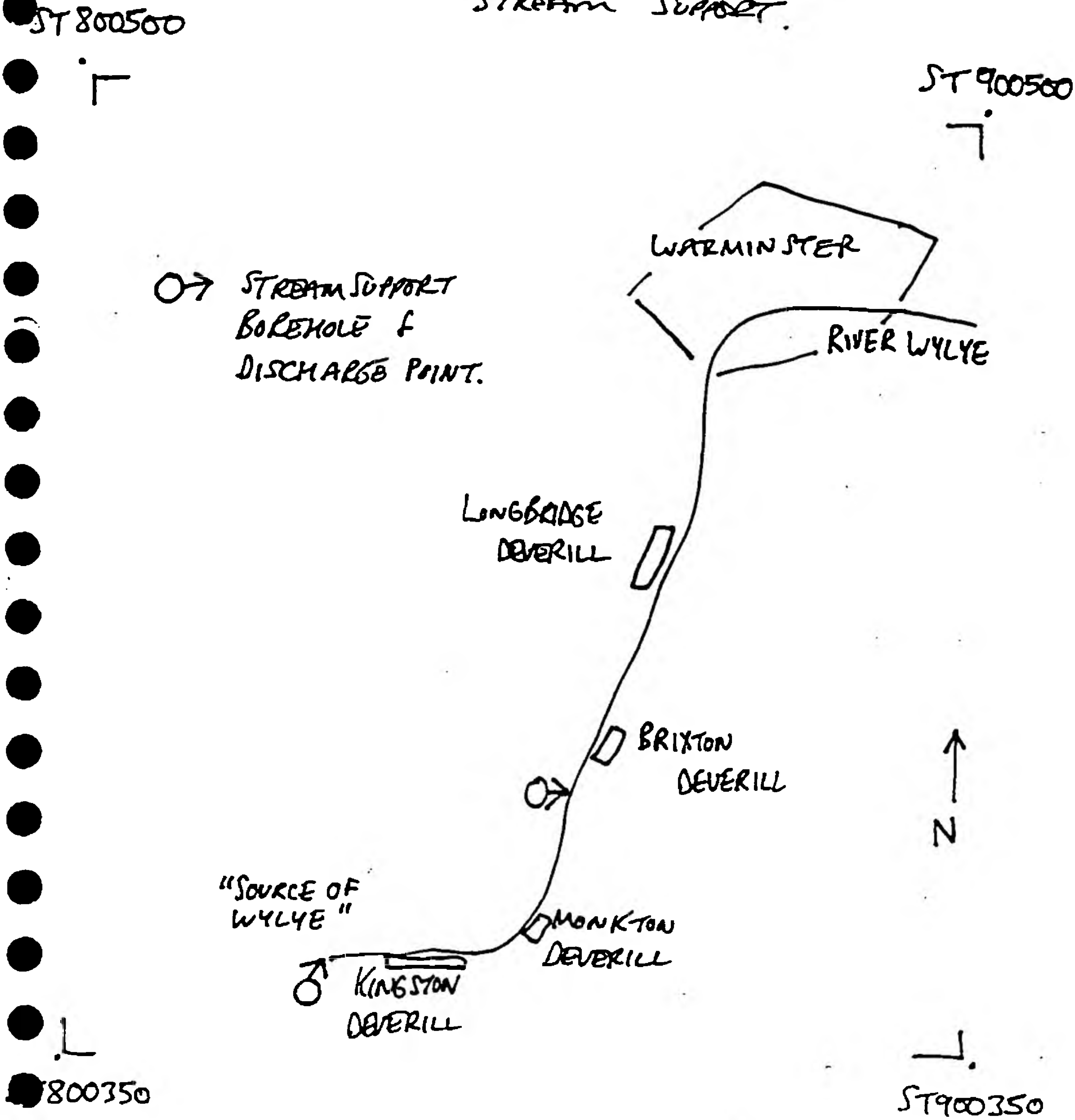
LIST OF REPORTS

SECTION 14 SURVEY
UPPER HANTS AVON PHASE 1 STUDY *
UPPER HANTS AVON PHASE 2 STUDY (CURRENT) *
* RESTRICTED CIRCULATION.

MALMESBURY GROUNDWATER SCHEME
STREAM SUPPORT AND RIVER FLOW



SCHEMATIC PLAN OF UPPER WYLYE STREAM SUPPORT.



WESSEX

30

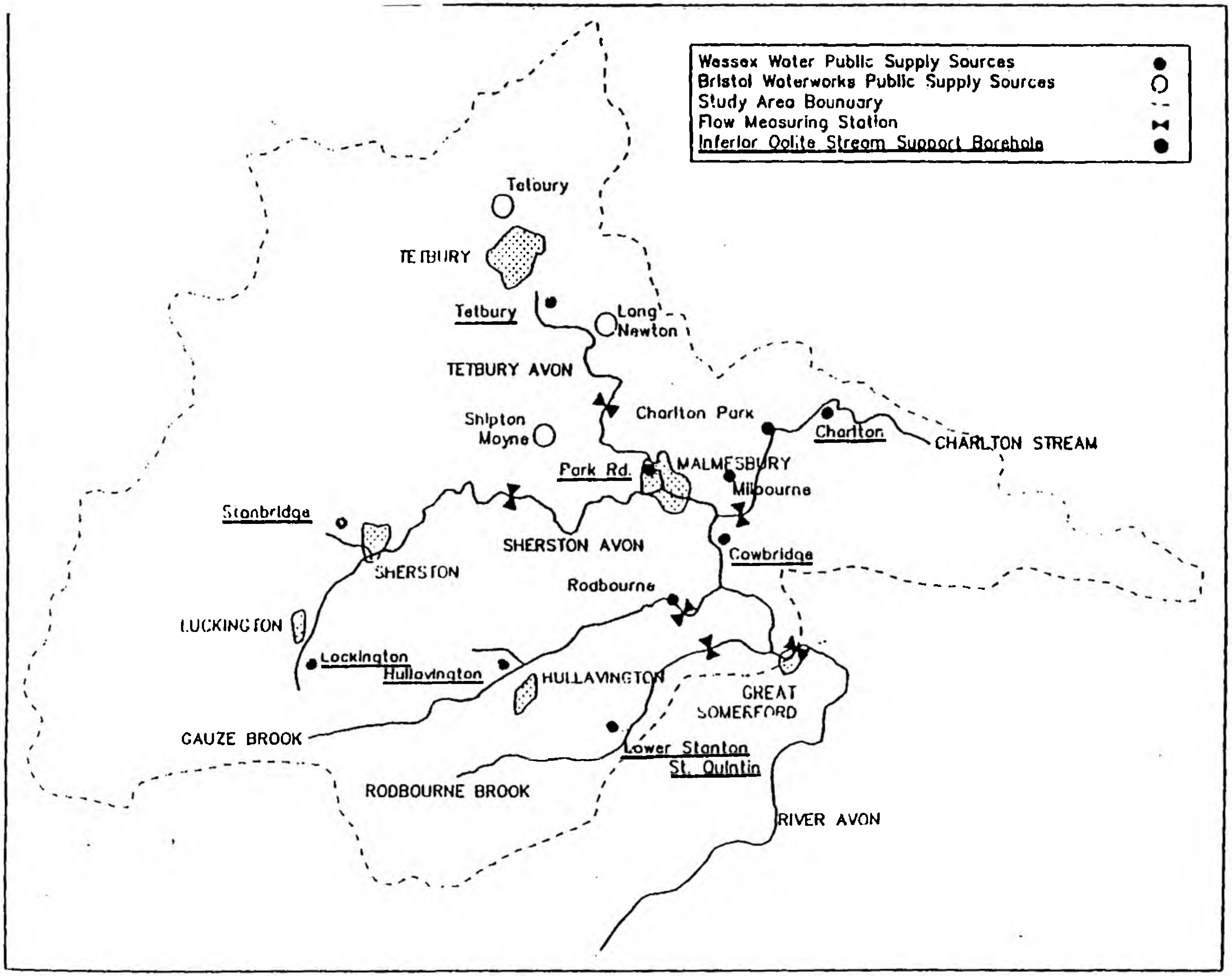
NATIONAL WATER RESOURCES STRATEGY
ENVIRONMENTAL ASSESSMENT

MALMESBURY AVON RIVER REGULATION SCHEME SUMMARY SHEET

SCHEMATIC MAP	ENCLOSED
OBJECTIVE	TO COMPENSATE THE EFFECT ON RIVER FLOW FROM THE GROUNDWATER PUBLIC WATER SUPPLY SCHEME
IMPLEMENTATION DATE	MALMESBURY LICENCE (WITH STREAM SUPPORT) ISSUED FEBRUARY 1981
PHYSICAL COMPONENTS	8 BOREHOLES & PUMPS AS SHOWN ON MAP. STREAMSIDE WITH PIPED DISCHARGES. STANDARD 2.5 ML/D PUMPS ENABLING SPEEDY REPLACEMENT IN CASE OF FAILURE.
FREQUENCY OF OPERATION	FOR PERIOD 1981 TO 1988 SEE FIGURE 1. FOR RECENT YEARS :

	1989	1990
HULLAVINGTON	JUL–OCT	MAY–DEC
LUCKINGTON	JUL–OCT	JUN–DEC
STANBRIDGE	JUL–OCT	JUN–DEC
TETBURY	JUN–OCT	MAY–DEC
CHARLTON	JUL–OCT	JUL–DEC
COWBRIDGE	AUG–OCT	JUL–DEC
LOWER STANTON	JUN–OCT	MAY–DEC
PARK ROAD	JUL–OCT	NONE

WITH / WITHOUT HYDROLOGY	MALMESBURY AVON IS SUBJECT OF LOW FLOW STUDY. STREAM SUPPORT EFFICIENCY WILL BE EXAMINED. NO CURRENT DATA.
PERCEIVED / MEASURED IMPACTS	
* GEOMORPHOLOGY :	NO IMPACTS
* PHYSICAL :	NO IMPACTS ON CHANNEL GEOMETRY CAUSED BY STREAM SUPPORT.
*WATER QUALITY :	OCCASIONAL WATER QUALITY PROBLEMS – RELEASE OF AQUIFER WATER TO RIVER HAS BEEN DISCUSSED. IMPROVED DILUTION - DETRIMENTAL
* NAVIGATION/AMENITY :	UNSIGHTLINESS & LOW FLOWS NOT PERCEIVED TO HAVE BEEN CAUSED BY STREAM SUPPORT.
* AQUATIC ECOLOGY :	THE SCHEME HAS MADE THE SITUATION NO WORSE THAN IT WAS.
*CONS/TERRESTIAL ECO :	NO RECORDED IMPACTS.
*FISHERIES :	GOOD FISH STOCKS REMAIN.
LIST OF REPORTS	SECTION 14 SURVEY WORKING PAPERS (WWA) WORKING PAPERS ON OVERALL SUPPLY SCHEME HELD BY NRA. MALMESBURY AVON MODEL & STUDY (CURRENT) IOH FLUVIAL GEOMORPHOLOGY UNIT STUDY (1980s)



Wessex Water Public Supply Sources
Bristol Waterworks Public Supply Sources
Study Area Boundary
Flow Measuring Station
Inferior Oolite Stream Support Borehole
Tetbury
TETBURY
Tetbury
Long Newton
TETBURY AVON
Charlton Park
Shipton Moyne
Charlton
CHARLTON STREAM
Park Rd.
MALMESBURY
Milbourne
Stanbridge
SHERSTON AVON
Cowbridge
SHERSTON
Rodbourne
LUCKINGTON
Luckington
Hullavington
HULLAVINGTON
GREAT SOMERFORD
GAUZE BROOK
Lower Stanton St. Quintin
RODBOURNE BROOK
RIVER AVON

APPENDIX G

Biological Banding

DOCUMENT HISTORY RECORD

Doc. No. 84.2470/ WP/ET/3122/NRA		Title: NRA National Water Resources Strategy : EA of Strategic Options Appendices			
Rev	Date	Description/Reason for Issue	By	Ckd	Appd
R01	29/10/93	For client comments			
R02	26/1/94	Final version to client.	JMC/ DI		

Ref: 84.247.0/WP/NRAHIS.R02

Biological Banding and Override for 1990

In 1988 IFE produced some suggestions for biological banding in a report for the DOE. The rules associated with this banding have been re-examined as part of the enquiry into biological banding for the 1990 survey.

As part of the Development of RIVPACS R and D project IFE have produced a further 4 suggestions for biological banding. These have been produced as a result of a re-evaluation of the original 438 sites on which RIVPACS was based and results of 3 seasons' samples and predictions on 4772 sites in the 1990 survey.

The biologists in each region were asked to evaluate the 5 options and combinations of options as far as their own regions are concerned.

As a result of their evaluation, option 5 was chosen as the basis for biological banding. This incorporates BMWP score, number of taxa and Average Score Per Taxon (ASPT). It is not possible to take any one criteria to represent the biological status of that site.

Option 5 utilises the Ecological Quality Index (EQI) formerly termed the Environmental Quality Index and defines band A's lower limit as the lower 5%ile of ASPT EQI, but the lower 10%ile for EQI (taxa) and EQI (score). Band widths of B and C are similar widths to Band A. D incorporates the remaining EQI's. It has been suggested that a further band, E, be included in the biological classification to encompass situations where no BMWP taxa are found.

The band criteria are given in the following table:-

Biological Class	EQI-ASPT	EQI-taxa range	EQI-score range
A	≥0.89	≥0.79	≥0.75
B	0.77-0.88	0.58-0.78	0.50-74
C	0.66-0.76	0.37-0.57	0.25-0.49
D	≤0.65	≤0.36	≤0.24
E	No BMWP taxa present.		

The final designation of biological quality (stress) is determined on the basis of all EQI values for that site (and taking into account the suitability of the site for RIVPACS prediction). The final class is the median of the 3 results e.g. B, B, C results in a B class, B A C results in a B class. There are some departures from this with regard to ASPT. If the lowest EQI is that for ASPT, then this will be the final class (so C, B, B results in a C class, D, C, B results in a D class).

The designations A B C D E are given for the biology classes where the suitability for prediction at a site is good (indicated on the RIVPAC program by a 1). Where the suitability for prediction is not so good (i.e. suitabilities 2 to 5) then designations are in lower case - a, b, c, d and e.

It was agreed by the biologists that, besides being used for the biological classification, this banding should be the basis for the biological override.

Although there are five biological classes and five chemical classes in the proposed NRA scheme, under no circumstances should they be considered equivalent. The biological indexing is based on a different and larger set of parameters than the chemical classification which is sanitary-determinand oriented.