RIVER DEE

WATER RESOURCES STRATEGY

CONSULTATION DOCUMENT

AAC

NRA

Guardians of the Water Environment

Diogelwyr Amgylchedd Dŵr

NATIONAL RIVERS AUTHORITY

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EXECUTIVE SUMMARY

Background

This discussion document has been prepared to assess the current and future operation of the River Dee regulation scheme. As a major strategic source of water for public supply and other related uses, it has been the focus of investigations to enhance resources over many years. This report identifies current and future management options, both within the Dee catchment and the catchments around its border. It is intended that it will provide the impetus to examine in more detail the preferred options which emerge from this study.

River Dee Regulation

Regulation of the River Dee has been undertaken since Thomas Telford constructed a sluice at the outlet of Bala Lake. With this control, low flows were augmented to guarantee a supply of water into the Llangollen Canal. Subsequent developments have led to the position today where the River Dee is probably the most regulated river in Western Europe.

Three reservoirs in the upper Dee catchment store water which is released to the river at times of need. These releases ensure that abstractions of over 859 Ml/day can be made. Five "Designated Abstractors" (Dŵr Cymru, North West Water, Wrexham Water, Chester Waterworks and British Waterways) operate nine river intakes between Berwyn (near Llangollen) and Chester. Additionally, water releases support environmental requirements and maintain a residual flow target at Chester Weir.

Of the water licensed for abstraction 88% is exported outside the Dee catchment area. Only about 5% of the licensed abstraction can be returned to the River Dee as effluent upstream of Chester Weir.

The Recent Situation

The River Dee system yield was last enhanced some twenty years ago with the completion of Llyn Brenig. This has now been almost fully licensed to individual Water Companies to meet growing public water supply demands.

The yield of the Dee system has recently been reviewed using an improved methodology. This is based on simulating the operational behaviour of the system since early this century at different demands levels. This method also identifies the frequency of temporary water conservation measures. These are associated with the incidence of less severe droughts, and the maximum durations (in years) for which reservoirs would be drawn down. The simulation study has highlighted some concerns with respect to these last two criteria in future years, as the Dee abstraction approaches the safe yield.

In the winter following a single dry summer (eg 1984,1989,1995) there is a significant chance of Llyn Celyn and Llyn Brenig (and Alwen and Vyrnwy direct supply reservoirs) not refilling naturally. Currently, there are no permanent facilities to enhance their refill by transferring water from elsewhere. This leads to potentially serious resource problems during the following summer, and around once in 30 years there will be a significant storage deficit at the start of that season.

Reservoir control rules for winter (refill curves, to specified probability) would identify when assisted refill is required. Contingency plans, and necessary facilities and abstraction licences, must be available if the system is to be robust enough to cope with 18-month drought events.

Accordingly, in looking at possible future resource developments on the Dee, many schemes have been identified. These will not only provide moderate increases in yield, but could also:

* reduce the frequency of water conservation measures associated with Dee regulation (in particular, the long average refill period for Llyn Brenig).
* facilitate improved conjunctive use of the Dee regulation with other resource systems, within and adjacent to the Dee, including Lake Vyrnwy, Shropshire (Perry) groundwater and the Llangollen Canal.
* provide improved refill capability for one or more of the 18-month critical reservoirs (Celyn, Brenig, Alwen or Vyrnwy).
* help in dealing with identified issues in the Catchment Management Plan, eg:
  - reducing the problems of low flows and groundwater mining associated with past over - abstraction from the Triassic sandstones in the Tower Wood area.
  - variability of pH in Afon Alwen, due to discharges from Llyn Brenig and Alwen reservoir.

The options which would enable these benefits to occur are looked at in detail within the body of the report. It is important to note, however, that the schemes are only options at this stage. Any developments would be preceded by detailed studies to assess impacts on the aquatic environment, operational constraints of existing supply systems, costs and benefits.

Consultation

Those with legitimate interest in the management and use of the Dee and associated water resources schemes are invited to make comment on this report. This participation is seen as vital to ensure appropriate and effective management of this strategic water resource as we approach the 21st century.

A seminar will be held on 28th February 1996 to enable full discussion on this document. The invited audience will then have until the 31st March to make written comments on the document. A final strategy will then be produced.

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1. INTRODUCTION

1.1 The Role of the NRA

1.1.1 The Water Act 1989 converted the ten regional Water Authorities into privatised water and sewage undertakers, and created a powerful environmental regulator - the NRA. Many separate statutes (primarily the Water Act 1989 and the Water Resources Act 1963) were consolidated into the Water Resources Act 1991. This is currently the main statutory framework for our duties and powers, including those for water resources.

1.1.2 The Environment Agency is due to come into being in April1996. As one of the existing bodies that will make up the new Agency the NRA's policies for sustainable development and water conservation will take on a greater significance.

1.1.3 The NRA has general environmental duties in relation to all its functions, including the need to maintain and improve fisheries and further conservation. It is responsible for the licensing of abstractions from surface and groundwaters and has a duty to secure the proper use of water resources. This duty includes assessing the need for new developments and ensuring that the most appropriate schemes are licensed.

1.1.4 The NRA generally maintains an appropriate distance between itself as regulator and the development and operation of sources. It is the responsibility of the water companies to provide an adequate supply of wholesome water to the public via the mains distribution system. The NRA has to have particular regard to the duties imposed on water companies. It is the NRA's role to regulate the water companies and other legitimate users of water. In doing so, a balance has to be struck between the needs of the environment and those of abstractors. In achieving a "balance" the NRA will ensure that international and national nature conservation sites will be given priority attention.

1.2 Background

1.2.1 Regulation of the River Dee has been undertaken since Thomas Telford constructed a sluice at the outlet of Bala Lake. With this control, low flows were augmented to guarantee a supply of water into the Llangollen Canal. Subsequent developments have led to the position today where the River Dee is probably the most regulated river in Western Europe. Each day four water companies are entitled to abstract up to 830Ml directly from the river in its lower reaches. (Table 1.)

1.2.2 Details on the regulation of the Dee are covered in Appendix B. Simply put, three sources in the upper Dee catchment store water which is released to the river at times of need. These releases ensure that abstraction and environmental requirements are met and a residual flow target at Chester weir maintained. Additional releases for recreation, fisheries and water quality are also provided. During wet weather the scheme is used to mitigate flooding, with Llyn Celyn and Llyn Tegid used to retain runoff for subsequent release when downstream flows have subsided.

1.2.3 Until 1989 operational regulation of the Dee was undertaken by the Welsh Water Authority under the statutory powers of the Dee and Clwyd River Authority Act of 1973. This act provides for the setting up of a Dee Consultative Committee. The committee's purpose is to comment on and help the Operators in formulating the operating rules of the scheme known as "Dee General Directions"

(DGD). Details on these are contained in Appendix B. For drought periods more severe than the design drought (which is set at 1 in 100 years), the committee can approve reductions in prescribed flows or abstractions.

1.2.4 With the privatisation of the water industry in 1989, ownership of the Llyn Celyn, Llyn Brenig and Alwen Reservoir fell to Dŵr Cymru. Operation of the Bala sluice, which controls the outflow of Llyn Tegid and hence the regulation of the Dee, became the responsibility of the NRA. To overcome any difficulties this may have createda Section 20 "Operating Agreement" between Dŵr Cymru and the NRA was promoted.

1.2.5 Abstractions by five "Designated Abstractors" takes place at nine river intakes between Berwyn (near Llangollen) and Chester :

Table 1.

COMPANY	LOCATION	LICENCE	Ml/Day
North West	Horseshoe Falls	24/67/5/57	50.006
	Huntington	24/67/9/147	
	Heron Bridge	"	
	Dee Bridge	"	686.446
	Company Dee Total	**(linked Licences)**	**709.176**
Wrexham Water	Berwyn	24/67/5/6	1.868
	Bangor is y coed	24/67/7/5	
		24/67/7/182	37.821
	Company Dee	**Total**	**39.689**
Chester Waterworks	Barrelwell Hill	24/67/9/3	34.033
Dŵr Cymru	Poulton	24/67/9/148 & 165	48.000
British Waterways	Horseshoe Falls	Unlicensed	28.340
		TOTAL	859.238

1.2.6 The abstractions by North West Water and British Waterways remove water for use outside the catchment. However, not all the water discharged into the Llangollen Canal by both British Waterways and North West Water is lost to the Dee. There are overspills at Black Park Brook (Chirk) as well as leakage and seepage throughout the length of the canal (Llangollen to New Marton). Wrexham Water returns are made back to the River Dee upstream of the major abstractions. Chester Waterworks returns are downstream of Chester Weir, therefore aiding the tidal section but are of no benefit to abstractors. Dŵr Cymru water is used mainly on Deeside and most is returned to the estuary, although some reaches the lower Afon Alyn as treated sewage effluent.

1.2.7 The Dee catchment also contains several other reservoirs, by far the largest of which is Alwen Reservoir. This is situated to the west of Llyn Brenig and is used for direct supply, via the Alwen aqueduct, to Deeside. It is owned and operated by Dŵr Cymru.

Table 2.

COMPANY	LOCATION	LICENCE	Ml/Day
Dŵr Cymru	Alwen Reservoir	24/67/4/16	45.46

1.2.8 Appendix C provides a table of all current major sources in the Dee and associated catchments.

1.2.9 As a consequence, over 88% of the water licensed to be abstracted is exported outside the Dee catchment area. Furthermore, only about 5% of the licensed abstraction can be returned to the River Dee as effluent upstream of Chester Weir.

1.3 The Recent Situation

1.3.1 The additional yield provided to the Dee system by construction of Llyn Brenig 20 years ago has now been almost fully licensed. However, the yield is not yet fully utilised - particularly by North West Water. An extension to Huntington Water Treatment Works, near Chester, of around 74 Ml/day would be needed before it could be fully used. This work is likely to be undertaken during 1996 enabling North West Water to abstract their full licence entitlement. Completion of these works would see the full design yield of the Dee system (13.5 cumecs) realised.

1.3.2 Areas in north Wales served from the Dee are now achieving low leakage levels, but North West Water leakage levels are higher. Table 3 identifies the losses for each Company.

Table 3.

Company	Losses in Litres/property/day
Dŵr Cymru (Dee)	122
Wrexham Water	73
Chester Waterworks	152
North West Water (Liverpool & Merseyside)	373

1.3.3 Compulsory metering of new households is practised by North West Water, Chester and Wrexham water companies. Dŵr Cymru, however, only install boundary boxes and leave the choice to the householder. To control underground supply pipe losses to the same standard as metering Dŵr Cymru undertake district metering of small groups of properties (average 330). National studies have indicated average savings of 11% in consumption because of metering. The individual studies however, show marked variations in savings which suggests the 11% average figure should be treated with caution.

Table 4.

Company	1994 Measured Household %	2021 Measured Household %
Dŵr Cymru	2.52	3.38
Wrexham Water	6.28	18.72
Chester Waterworks	2.70	18.80

1.3.4 "Stage 1" Drought General Directions allow for the reduction of the residual flow over Chester Weir from the normal 4.2 cumecs to natural flow: (2.2 to 3.5 cumecs downstream of Chester Sewage works effluent discharge). These would occur around 1 in 6.2 years on average at the 1995 maintained flow of 12.5 cumecs. Llyn Brenig would have a 4-year maximum drawdown period (1933-37).

1.3.5 At the maintained "Licensed" flow of 13.5 cumecs, the frequency of "Stage 1" Drought General Directions would increase to 1 in 3.3 years on average. The maximum Llyn Brenig drawdown period would also increase to 9.5 years. This is shown graphically in Figure 1. A full explanation of the reliability of refill is given in Appendix E. The 13.5 cumec yield is likely to be achieved during 1996 with the completion of the recently announced planned expansion of the Huntington Treatment Works by North West Water.

1.3.6 **The NRA does not believe that a 1 in 3.3 year frequency of restrictions and an almost ten-year reservoir drawdown period are acceptable standards of service for the Dee abstractors.**

1.3.7 Environmental and low flow/groundwater problems in the Dee catchment have been identified in the Catchment Management Plan Consultation Report (June 1994). Table 5 provides a summary of these; identified by the Issue number in the Catchment Management Plan (CMP)

Table 5.

Catchment Name	Location	Issue No :	Description of Issue
Aldford Brook	Right bank tributary of Lower Dee.	37	Falling groundwater levels and baseflow.
Worthenbury Brook	Right bank tributary of Lower Dee.	38	Falling groundwater table.
Afon Clywedog	Left bank tributary flowing through Wrexham.	39	Low flows due to old mine drainage and PWS abstraction.
Dolfechlas Brook	Left bank of the Afon Alyn.	40	Low flows possibly due to abstraction.

1.4 Present and Growing Concerns

1.4.1 A long-term groundwater level recession created by abstractions at the catchment boundary remains unresolved. The abstractions by Severn Trent Water occur on the boundary of three NRA Regions (Welsh, North West, Severn Trent). There has been a 5Ml/d reduction in Aldford Brook flows (a right bank tributary of the lower Dee) in the last 15 years. A similar problem may be developing in the Worthenbury Brook catchment. As well as reducing the safe yield of the Dee, these flow reductions have a major influence on the flora and fauna of the tributaries.

1.4.2 Recent research shows the frequency of "Stage 1" Drought General Directions Stage 1 would increase to 1 in 3.3 years as Dee abstractions approach licensed yield. At this 13.5 cumec level a 10-year maximum drawdown of Llyn Brenig would also occur in sequences of dry years such as 1933 to 1943.

1.4.3 The question of how to deal with the unknown date of the end of a major drought, when defining yields, is unresolved. The above yields assume the end-date in any particular event is known.

1.4.4 The largest abstractor, North West Water, also takes a major direct supply from Lake Vyrnwy (situated in the Severn catchment to the South). There is no formal conjunctive use strategy with the Dee System storage.

1.4.5 Lake Vyrnwy has the ability to regulate the river Severn. The reservoir is identified by the NRA National Strategy as a potential regional source for Severn/Thames transfers. This assumes that take-up of the unused North West Water licence on the Dee would entail no extra costs or problems for NRA Welsh Region and other Dee abstractors.

1.4.6 However, any significant reduction of the Vyrnwy direct supply to NWW could trigger increased Dee abstraction. This in turn would lead-to a higher frequency of Drought General Directions. They would rise to 1 in 3.3 years on average as the full 13.5 cumecs yield is reached. This would imply costs and problems to Welsh Region NRA and Dee abstractors, if this frequency triggered standards of service problems, and is therefore unacceptable.

1.4.7 The latest NRA national forecast suggests that Vyrnwy partial redeployment for Severn/Thames transfer will not now be required for many years. The proposal to construct a storage reservoir at Abingdon in the Thames is still being considered.

1.4.8 With the granting of Dŵr Cymru's recent licence application to increase abstraction at Poulton, there is now no significant yield left on the Dee. Therefore, is it appropriate to construct new works to increase yield, or improve standards of service, whilst North West Water has spare licensed capacity?.

1.4.9 The major reservoirs (Celyn, Brenig, Alwen, Vyrnwy) do not always refill in winter. In 18-month droughts (eg. 1933/34) Celyn/Brenig would have been only 38% full on 1st May, 2nd summer, at the 13.5 cumec full yield. Such a position would imply major restrictions on use in the second summer, and in subsequent years.

1.4.10 Variable pH in the water of the Afon Alwen arises from Alwen reservoir and Llyn Brenig operation and releases. This has had a detrimental impact on fish stocks downstream, particularly when most of the flow consists of water released from Llyn Alwen. Investigations into the impact of pH on salmonid fisheries are currently underway.

1.4.11 Chester sewage effluent is a significant unused resource of around 27 Ml/d. The NRA National and Regional Strategies, and the Dee catchment plan promote the same message. "Abstractions should be made as far downstream in a river as possible with water returned as close to the point of abstraction as possible". There are, however, concerns on water quality grounds, about pumping Chester STW effluent back to, or upstream of, Chester Weir. However, it this was to occur it could be counted as re-abstractable, or treated as part of the residual flow.

1.4.12 An algal bloom incident occurred in Llyn Tegid in the summer of 1995, prompting a transfer of water from Llyn Celyn. The use of the scheme to solve water quality problems highlights the environmental benefit that can come from river regulation. However, the only other recorded algal bloom occurred in 1947.

1.5 Possible Baseline NRA Welsh Region Requirements

1.5.1 The Dee regulation scheme was used to assess the recently completed "Surface Water Yield Methodology" R & D project. Prior to this project it was assumed that up to 72 Ml/day yield was available above that already licensed. This assumption was based on work undertaken some time ago using a limited length of flow record. However, the recent review has used longer and better flow records. As a result it has shown that at the current level of service, with restrictions commencing in a 1:100 drought sequence, no additional yield is available. (see 2.1.4)

1.5.2 Additionally, the current operational practice results in a drawdown period for the Dee reservoirs of 10 years. Using the "design drought" the drawdown period of the Dee system would last from Spring 1933 to Spring 1943, even with Dee General Direction restrictions in force. If this type of weather pattern were to be repeated, the combined Celyn and Brenig storage would not reach a full state for 10 years. This falls outside the standards employed in other Regions where yield has been assessed based on a maximum five year reservoir refill constraint. If this practice were to be adopted on the Dee, current yield would be less than current licence entitlement.

1.5.3 The 1995 summer and autumn have closely mirrored the rainfall patterns of 19933/34 in the Dee catchment. The potential for a repeat of the worst drought sequence is therefore quite high.

1.5.4 All options presented in this report are subject to environmental acceptability. Each would be subject to a detailed Enyironmental Assessment, and many would require planning consent.

1.6 Meeting Future Public Water Supply Demands

1.6.1 Future demands for public water supply are built up using several components. These include population growth, personal water use, numbers of dwellings and levels of occupancy, industrial supplies, water losses in distribution and supply pipes, and demand reduction measures. Each of these components is assessed over the planning period (1994 to 2021), and then combined to give a demand prediction. By altering the assumptions used for certain components, demand scenarios for "High" and " Low" growth have been produced

1.6.2 These forecasts have been compared with the volumes the water supply companies can reliably obtain from their sources - the yield. This provides the ceiling beyond which new resources would need to be developed to meet extra demands. The yields used in this exercise have been agreed with the water companies. They were then reduced marginally to take account of "outage". This is the

loss of sources due to planned or unplanned maintenance, and the temporary loss of supply due to pollution. This reduction has been assigned using the guidance provided through recent research into "Outage Allowance for Water Resources Planning " conducted by the UK Water Industry. No reduction has been included to take account of changing public perception towards levels of service provided to customers of the water service companies.

1.6.3 The demand management options and growth assumptions used to produce the demand scenarios are identified in Table 6.

1.6.4 Both the"High" and "Low" scenarios assume domestic metering to increase at the same rate as predicted by the water companies (see Table 4.)

1.6.5 The methodology employed to produce the forecast scenarios is the same as that used in "Water - Nature's Precious Resource", the NRA's National strategy published in 1994. This component method is a technique used widely in the water industry for PWS demands. The assumptions used by individual companies and the NRA regarding rates of growth of components can vary considerably, owing to many factors such as local conditions. Despite this, the forecasts recently produced by the water companies for the Office of Water Services (OFWAT) are broadly in line with the NRA scenarios.

Table 6.

		Assumptions for each Scenario		
	Assumption	High	Low	Broad Area of Effect
1.	Growth of per capita consumption (pcc) by compound annual rate of 1%. Per capita figures constrained to a maximum of 189 litres/head/day.	●		Per Capita Consumption Growth.
2.	Growth of per capita consumption by compound annual percentage rates derived from Binnie & Herrington (1992). Per Capita figures are constrained to a maximum of 180 litres/head/day		●	
3.	Growth in metered and unmetered non-household consumption by compound annual rate of 0.75%	●		Commercial Growth
4.	No growth in metered and unmetered non-household consumption above existing levels.		●	
5.	No increase in the proportion of domestic metered properties above the levels indicated by the Water Companies over the planning period	●	●	Metering
6.	Leakage levels to gravitate towards 290 litres/property/day -at a rate of 10 litres/property/day/year; to simulate low leakage levels of service.	●		Leakage
7.	Leakage levels to gravitate towards 120 litres/property/day {North East Wales, Chester and Wrexham} -at a rate of 20 litres/property/day; to simulate higher leakage levels of service.		●	

1.6.6 The range between the High and Low demand scenarios shows the significant impact that different basic assumptions make on the need for additional water resources. The NRA believes that the Low scenario is likely to be the course that demands in the Welsh Region will follow because:

* it incorporates demand management measures that are considered the minimum necessary in areas where resources are under stress. The absence of the improved demand management measures inherent in the forecast is unacceptable.
* many of the increases are based on industrial demand. Local demands can change dramatically with the siting of new industries. However, experience has shown that demand at a water company "area" level is unlikely to grow at the rates forecast in the high scenario.

1.6.7 Peak demands are short term increases in water demand and have an important influence on the need for and timing of new resource developments. They arise from summer use of water, such as garden watering, or due to cold weather impacts on the distribution network such as pipe bursts. Peak demands have been forecast using a peak week factor derived from water company experience during the summer of 1995. This is considered a good indicator of the likely peaks that could be expected over the planning period. Standards of service for the water undertakers allow for the suppression of peaks through measures such as hosepipe bans once in every 10 years. Although neither measure was needed in the Region in 1995, the summer of 1995 is regarded as having been more severe than a 1 in 10 year event.

1.6.8 To meet peaks, water companies provide local service reservoirs and water towers, or provide interconnections between supply zones to enable transfer of water from several sources. Where this flexibility cannot be provided, additional water resources may need to be sought.

1.6.9 An area that has not been addressed is where resource developments are pursued by the company to reduce current operating costs. This includes closure of sources due to costly water treatment, and the enhancement of existing, or construction of new, resources to save costs. Such schemes may benefit the company promoting the change, its customers, and indeed the country as a whole through lower energy or chemical uses. However, these factors are not covered in normal water resources planning and as such cannot be accommodated in the demand forecasts.

The Predicted Average Supply Deficits (Ml/day):

Table 7.

	Forecast	1996	2001	2006	2011	2016	2021
Dŵr Cymru	Low						
	High					0.13	2.94
Wrexham	Low					0.08	1.33
	High		3.33	8.71	13.37	15.88	17.60
Chester	Low						
	High			2.81	5.16	6.92	8.07

The Predicted Peak Day Supply Deficits (Ml/day):

Table 8.

	Forecast	1996	2001	2006	2011	2016	2021
Dŵr Cymru	Low						
	High						
Wrexham	Low						
	High					2.66	4.84
Chester	Low			0.50	1.41	2.51	3.66
	High	1.57	5.82	10.02	12.84	14.95	16.34

KEY

	Suggests a surplus of resources

1.6.10 Additionally, Wrexham Water has agreed to take steps to alleviate an ALF problem on the Afon Clywedog in Wrexham, by transferring their current abstraction to the Dee. This will have only a limited effect on the current yield of the Dee. The existing and proposed abstractions are both from the Dee catchment and much of the water is returned to the River Dee downstream of Wrexham.

1.6.11 Adoption of the "Low" scenario forecast, with its inbuilt demand and resource management measures, still fails to meet the potential future demand. In all cases the companies in the Dee catchment have no option other than to look to the River Dee to meet these future requirements. Additionally, it is prudent to identify possible schemes that might provide:

i) improvements in the reliability of current supplies, particularly in respect of the lessons of the summer of 1995.

ii) more efficient and/or more environmentally acceptable schemes to replace existing ones.

iii) further resource management opportunities through such options as "Conjunctive Use", "Effluent Recycling" and "Re-allocation of Water".

iv) new additional resources for the benefit of the Region, and beyond.

1.6.12 North West Water currently does not have the capacity to abstract their full licence entitlement. Consequently, around 73 Ml/d of their licence is unused. Discussions with the company suggest that no further water, above that already licensed, will be needed over the next three decades.

2. DEE CATCHMENT OPTIONS

2.1 Background

2.1.1 Conjunctive use of different sources has, during the last 30 years, been a feature of regional policies to improve the use of existing resources. The three Dee regulation sources - Llyn Tegid, and Llyn Celyn and Llyn Brenig reservoirs - have markedly different storage and refill characteristics.

2.1.2 When sources are operated conjunctively, the yield and environmental safeguards are substantially greater than would be obtained if they were to be operated separately. The operational management of the Dee has been refined to the point where few further significant efficiency or environmental gains are likely to be achieved.

2.1.3 The existing public water supply yield of 830 Ml/d from this system, which was last enhanced some twenty years ago with the completion of Llyn Brenig, has now been almost fully licensed. The NRA's demand forecasts show that, under the "Low" scenario, the small current surplus in scheme yield will be used (Tables 7 & 8.). The "Low" growth scenario (Table 6) assumes that NRA's current tightest leakage control scenarios will be achieved by the Dee abstractors.

2.1.4 The yield of the Dee system has recently been reviewed using an improved methodology. This is based on simulating the operational behaviour of the system at different demands over historic periods since early this century. This method also identifies the frequency of temporary water conservation measures. These are associated with the incidence of occasional less severe droughts, and the maximum durations (in years) for which reservoirs would be drawn down. The simulation study has highlighted concerns with these last two criteria, as the Dee abstraction approaches the safe yield of 13.5 cumecs. (see Appendix A).

2.1.5 In the winter following a single dry summer (for example 1984,1989,1995) there is a significant chance of Llyn Celyn and Llyn Brenig (and Alwen and Vyrnwy direct supply reservoirs) not refilling naturally. This could lead to serious problems during the following summer. Providing a means of refill would remedy this problem on the occasions when winter rains are insufficient. However, there are no permanent facilities to achieve this. As a result there could be a significant storage deficit at the start of the summer approximately once every 30 years.

2.1.6 Reservoir control rules for winter (refill curves, to specified probability) would identify when assisted refill is required. **Contingency plans, and necessary refill facilities and abstraction licences, must be available if the system is to be robust enough to cope with 18-month drought events.**

2.1.7 Accordingly, in looking at possible future resource developments on the Dee, a number of schemes have been identified. These will not only provide moderate increases in yield, but could also:

* reduce the frequency of water conservation measures associated with Dee regulation (in particular, the long average refill period for Llyn Brenig).
* help improved conjunctive use of the Dee regulation with other resource systems, within and adjacent to the Dee. This includes Lake Vyrnwy, Shropshire (Perry) groundwater and the Llangollen Canal.
* provide improved refill capability for one or more of the 18-month critical reservoirs (Celyn, Brenig, Alwen or Vyrnwy).
* assist in dealing with identified issues in the Catchment Management Plan, for example:
  - reducing the problems of low flows and groundwater mining associated with past

over -abstraction from the Triassic sandstones in the Tower Wood area.
- variability of pH in Afon Alwen, due to discharges from Llyn Brenig and Alwen reservoir.

2.1.8 **It is important to note that the schemes listed below are only options at this stage. Any developments would be preceded by detailed studies to assess impacts on the aquatic environment, operational constraints of existing supply systems, costs and benefits.**

2.1.9 The "Key Map" showing the location of 8 Base Maps follows the list of options. These detailed maps are located together at the end of Section 2.

2.1.10 The pipeline lengths and static heads are derived from 1:50,000 OS maps. Water availability fugures are best estimates, quickly assembled. Further detailed work will be required for these ata later date. Appendix D lists those who have helped provide data or information for this study.

2.2 Listing of the Options Considered

OPTION 1: Dee Regulation/Severn Regulation Conjunctive Use Options (with British Waterways and possibly North West Water)

1A: Vyrnwy raw water main/Oswestry treatment works/Llangollen Canal
1B: Shropshire Groundwater (Perry catchment)/ Llangollen Canal
1C: Oswestry treatment works washwater/Afon Morda/Llangollen canal

OPTION 2: Llyn Brenig/Alwen Reservoir/Aled Reservoirs Conjunctive Use links (with Dŵr Cymru)

2A1: Link mains, Aled Isaf to Llyn Aled, and Llyn Aled to Alwen reservoir
2A2: Link main, Aled Isaf to Alwen Reservoir
2B : Link main, Alwen reservoir to Llyn Brenig

OPTION 3: Conjunctive Use: Surface and Sandstone Groundwater (with North West and Severn Trent)

Tower Wood Boreholes/Vyrnwy Aqueduct

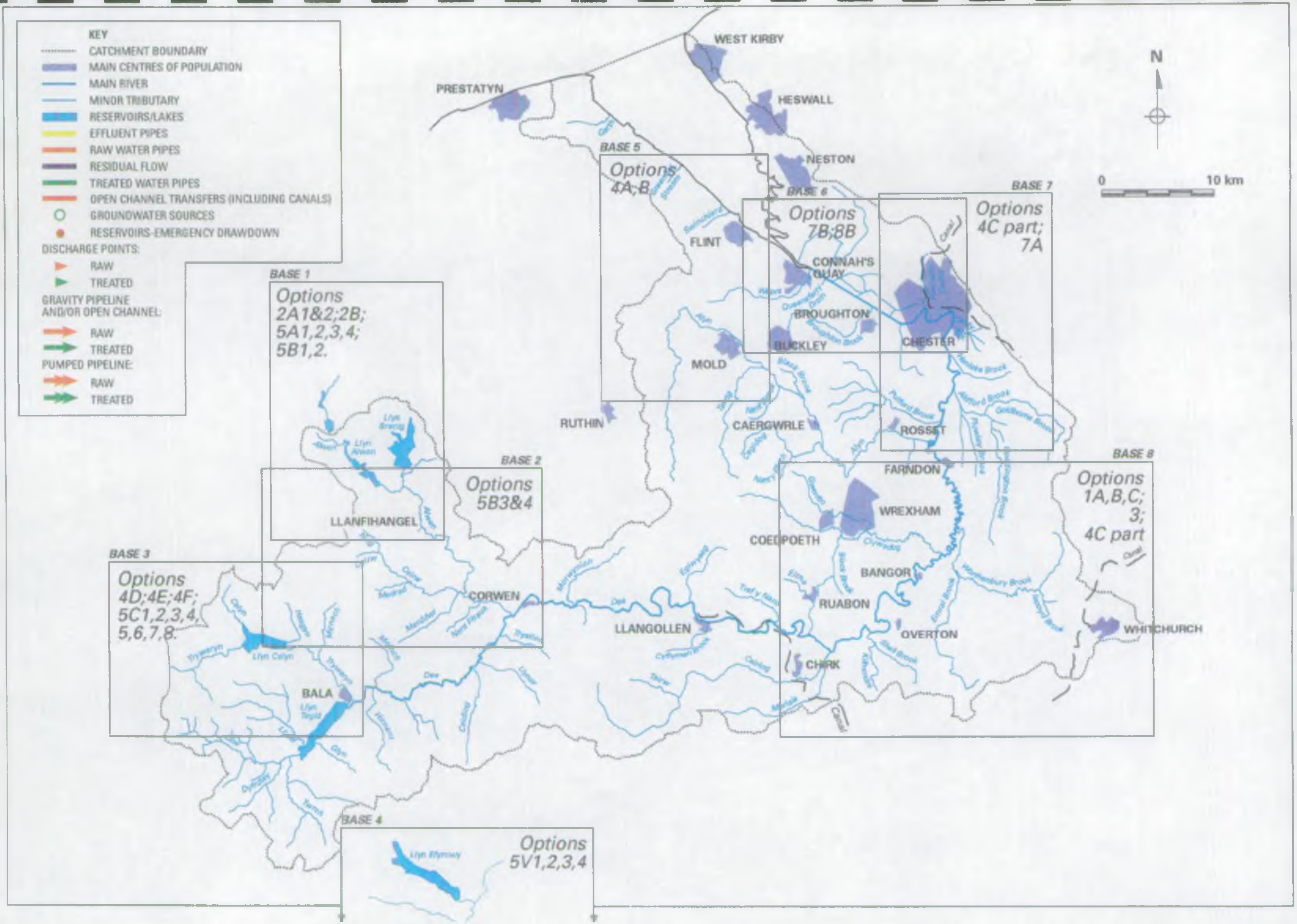
OPTION 4: Transfers into the Dee Catchment

4A: River Alyn
4B: Bagillt Tunnel to Alyn Transfer
4C: Shropshire Union Canal/Llangollen Canal
4D: Afon Conwy
4E: Llyn Conwy (Dŵr Cymru)
4F: Llyn Trawsfynydd (Nuclear Electric)

OPTION 5: Assisted Refill of major reservoirs

5A: Assisted Refill of Alwen Reservoir
5A1: Existing catchwater at Hafod-y-Llan Isaf
5A2: Pumping from Aled Isaf
5A3: From existing Brenig Stage II refill option (Llanfihangel)
5A4: Releases from Storage in Llyn Alwen

5B: Assisted Refill of Llyn Brenig
5B1: From Alwen Reservoir (link main)
5B2: From Llyn Brân
5B3: From existing Brenig Stage II refill options (Llanfihangel, Maerdy, Corwen)
5B4: From Llyn Celyn



KEY
CATCHMENT BOUNDARY
MAIN CENTRES OF POPULATION
MAIN RIVER
MINOR TRIBUTARY
RESERVOIRS/LAKES
EFFLUENT PIPES
RAW WATER PIPES
RESIDUAL FLOW
TREATED WATER PIPES
OPEN CHANNEL TRANSFERS (INCLUDING CANALS)
GROUNDWATER SOURCES
RESERVOIRS-EMERGENCY DRAWDOWN
DISCHARGE POINTS:
RAW
TREATED
GRAVITY PIPELINE AND/OR OPEN CHANNEL:
RAW
TREATED
PUMPED PIPELINE:
RAW
TREATED
N
0
10 km
WEST KIRBY
HESWALL
NESTON
PRESTATYN
FLINT
CONNAH'S QUAY
BROUGHTON
BUCKLEY
MOLD
CHESTER
RUTHIN
CAERGWRLE
ROSSETT
FARNDON
WREXHAM
COEDPOETH
BANGOR
RUABON
OVERTON
WHITCHURCH
CHIRK
LLANGOLLEN
CORWEN
LLANFIHANGEL
BALA
BASE 1
Options 2A1&2;2B; 5A1,2,3,4; 5B1,2.
BASE 2
Options 5B3&4
BASE 3
Options 4D;4E;4F; 5C1,2,3,4, 5,6,7,8.
BASE 4
Options 5V1,2,3,4
BASE 5
Options 4A;B
BASE 6
Options 7B;8B
BASE 7
Options 4C part; 7A
BASE 8
Options 1A,B,C; 3; 4C part
Llyn Brenig
Llyn Alwen
Llyn Celyn
Llyn Tegid
Llyn Efyrnwy
Dee
Alyn
Canal

5C: **Assisted Refill of Llyn Celyn**
- **5C1: Existing catchwater (Hesgin)**
- **5C2: Afon Erwent Catchwater**
- **5C3: Afon Conwy Catchwater/Llyn Conwy**
- **5C4: Llyn Trawsfynydd**
- **5C5: Llyn Arenig Fawr**
- **5C6: Llyn Arenig Fach, and Llyn Tryweryn**
- **5C7: Afon Mynach**
- **5C8: Pumped Refill from Llyn Tegid**

5V: **Assisted Refill of Vyrnwy Reservoir**
- **5V1: Existing catchwaters and Water Bank**
- **5V2: Pumping from Meifod**
- **5V3: Pumping from the Banwy**
- **5V4: Other Schemes to Enhance the Vyrnwy Water Bank**

OPTION 6 : Enhanced Reservoir Capacity

6A: **Llyn Celyn**

OPTION 7: Re-locating Effluent Discharges

7A: **Chester Sewage Works**
7B: **River Alyn**

OPTION 8: Emergency Measures

8A: **Drawdown of lakes/reservoirs below normal lowest level in 2nd Summer, 18 month drought**
8B: **Reduction of Residual Flows to Estuary**
- **8B1: Design Residual Flows in Dry Winters**
- **8B2: Design Residual Flows in Dry Summers**

OPTION 1: Dee Regulation/Severn Regulation Conjunctive Use Options (with British Waterways and possibly North West Water)

North West Water's Dee abstractions (709 Ml/d licensed, current treatment works capacity of around 635 Ml/d) are used to supply Liverpool and Merseyside. They are supplemented by direct supply abstractions from Lake Vyrnwy (248 Ml/d licensed, 195 - 215 Ml/d actually abstracted). NRA national strategy studies have looked only at re-allocation of Vyrnwy direct supply to river regulation. This would benefit Severn Trent and/or Thames NRA Regions but is now considered unlikely in the short to medium term. This provides an opportunity to review the benefits of conjunctive use of Vyrnwy and Severn regulation with Dee regulation.

Opportunities are likely to exist for improving yields and reliability. The Severn (regulated by Llyn Clywedog, Shropshire Groundwater and a 'Water Bank' in Vyrnwy), has only a single summer (6-month) critical period. This compares to the 18-month critical periods for Dee regulation and Vyrnwy direct supply. Instead of their operation being separate, as now, the decisions about which sources to use to regulate each river could be considered jointly. Celyn and Clywedog would remain as the 'workhorses' for the regulation of the rivers Dee and Severn in normal years. In drought events, however, the use of the other sources (Brenig, Vyrnwy water bank and Shropshire Groundwater) could provide greater flexible.

A feasible Dee/Severn conjunctive use scheme does not need to involve large inter-catchment transfers. The Dee and Severn catchments are linked by the Llangollen canal. Up to 50 Ml/d is abstracted from the Dee at Llangollen into the canal by North West Water. This is additional to British Waterways entitlement of 28 Ml/d. This then passes out of the Dee catchment at Chirk, and North West Water re-abstract their water at Hurleston water treatment works. Part, or all, of the Dee abstraction could be rested at times of need if an alternative source was available. Severn catchment sources could provide this.

A typical conjunctive use situation would occur in the second summer of serious 18-month droughts. Under these conditions there may be an urgent need to conserve releases from the Dee regulating reservoirs (notably Brenig). Regulating releases for the Severn could, however, be adequately met from Clywedog. All or part of the Hurleston abstraction could be supported by resting the Dee-abstraction and transferring into the canal from one or more of the following:

* **1A:** the Vyrnwy water bank, via suggested spare capacity in the raw water mains to Oswestry Water Treatment Works (WTW), and a new 9 km link main from the WTW to the Llangollen canal.

* **1B:** the Shropshire Groundwater (Perry) near Lower Frankton lock. Around 2 Ml/d of Dee water already flows by gravity into the Severn catchment, at this location. Additional water may require back pumping at Frankton.

* **1C:** 5 to 10 Ml/d of washwater from the Oswestry WTW, which currently runs into the River Morda, could be pumped back along the disused Montgomery Canal into the Llangollen canal. This would require back pumping at Frankton Locks and possibly major renovation of the Montgomery canal due to its high leakage levels. The loss of water to the River Morda would also need assessment.

Additionally, any of the transfer options would also allow moderate discharges to the Worthenbury Brook from the canal, supported by inputs from the Severn Trent Region. This will compensate for any future reduction of Worthenbury Brook flows due to the Shropshire Groundwater Scheme or Severn Trent's direct supply borehole at Kinsall.

The Llangollen Canal has some of the highest boat usage in the country with peak lockage of 10,000 per annum. A balance between navigation and water transfer would have to be struck.

OPTION 2: Llyn Brenig/Alwen Reservoir/Aled Reservoirs Conjunctive Use links (with Dŵr Cymru)

Dŵr Cymru's Dee abstractions are operated conjunctively with direct supply abstractions of 35 to 55 Ml/d from Alwen reservoir. The Aled regulating reservoirs (Llyn Aled and Aled Isaf) lie just to the north-west of Alwen reservoir.

Some conjunctive use management of Alwen and Brenig reervoirs already takes place, with the reduction of Alwen compensation water and increase of Brenig compensation water in dry summers. There are no links at present, however, between the Aled reservoirs and the catchment area of Alwen reservoir.

Option 2A: Link Main Between the Llyn Aled Reservoirs and Alwen Reservoir.

Alwen and the Dee regulation both have an 18-month critical period. Consequently, no increase in yield can be expected simply from construction of a link main between Alwen and Brenig. However, the Aled regulation system is single-summer critical, even though Llyn Aled does not refill in dry winters. Aled Isaf will also always refill and overflow, even in the driest winter (1933/34). There is therefore some scope for helping refill of Alwen (or Brenig) in a dry winter by pumping from Aled Isaf.

A link could be constructed between the south end of Aled Isaf and the Afon Alwen 0.5 km NW of Cottage Bridge (from where it flows into Alwen Reservoir). Calculations show that besides refilling Aled Isaf and Llyn Aled, and discharging compensation water from Aled Isaf, up to 1,500 Ml (17 cumec-days) is spare. Alwen reservoir could receive this even in a dry winter such as 1933/34. The static lift would be only about 15 metres, and the link would ensure refill of Llyn Aled (which does not occur now). It could also allow up to 400 Ml (4.6 cumec-days) summer or autumn flows of the upper Afon Alwen (5km^2 catchment area) to be diverted by gravity into the Aled reservoirs. This could be a useful bonus. There are two options to link the south end of Aled Isaf to the Alwen near Cottage Bridge:

* **2A1:** a continuous 2.5 km pumped main from Aled Isaf to the Afon Alwen, with a facility to discharge into Llyn Aled en route
* **2A2:** a 1 km pumped main from Aled Isaf into Llyn Aled, and a new sluice with gravity overflow at the south end of Llyn Aled linked to the Afon Alwen by a 0.6 km long pipeline

The latter option would allow gravity overflow of Llyn Aled into Alwen, whenever appropriate. The loss of water downstream of Aled Isaf reservoir may have knock-on effects on the Afon Aled and Afon Elwy.

Option 2B: Two-way link main, Alwen Reservoir to Llyn Brenig

The purpose of a 3 km link main between Alwen Reservoir and Llyn Brenig would be to promote flexibility for year-to-year operation. It would also cover a wide range of possible emergency scenarios such as an accidental pollution of Alwen Reservoir. NRA objectives for these two links would be to:

i) ensure consistent quality of compensation water discharges in summer by using Llyn Brenig water for all summer compensation water discharges, including those downstream of Alwen reservoir.

ii) minimise overflows from Alwen reservoir by maximising direct supply abstraction, with transfers from Brenig when necessary**.

iii) reduce duration of Llyn Brenig drawdowns by pumping potential winter overspill from Alwen (and Aled Isaf) into Llyn Brenig (13 metres static head) when appropriate.

Incidental hydropower generation could help in funding capital and running costs. A short simulation study is required to test the effect of changing to this suggested method of operation.

The differing qualities of Alwen Reservoir and Llyn Brenig water will need to be carefully considered.

** *At present, Dŵr Cymru take at 50 to 55 Ml/d (150% of the safe yield) until control rules specify cutback (usually after three months of a dry summer) to the 18-month safe yield (37 Ml/d plus compensation water).*

Dŵr Cymru then increase their Dee abstraction by the amount of cutback (typically 13 to 18 Ml/d). This requires extra discharges from Llyn Brenig, and extra flows of 0.15 to 0.22 cumecs down the Afon Alwen and the Dee, during the summer. When the winter rain occurs, Alwen refills and generally overflows.

The existence of transfer facilities by gravity from Llyn Brenig to Alwen Reservoir could allow Alwen to be overdrawn to lower control rules without undue risk. This would maintain the maximum abstraction rate for longer, thus helping to achieve the objective of minimising Alwen reservoir overflows.

OPTION 3: Conjunctive Use: Surface and Sandstone Groundwater (with North West and Severn Trent)

For over thirty years, over-abstractions by Severn Trent Plc and their predecessors from boreholes in the sandstone at Tower Wood have significantly depleted groundwater levels. Baseflows in the Aldford Brook, sustained by groundwater, have reduced by around 5 Ml/d in the last 15 years. As pumping levels in the supply boreholes have fallen, the abstraction has reduced from 11 to 5 Ml/d. A simple calculation suggests that a storage depletion of at least 5,000 Ml (58 cumec-days) has developed in the aquifer.

In the rest of the Cheshire sandstone aquifer, in North West NRA Region, public water supply abstractions by North West Water from the sandstone have been reduced. North West Water's Dee and Vyrnwy water have made up the difference. This has not happened at Tower Wood, because of administrative boundary complications. The abstraction is by Severn Trent Plc, the problem is in NRA Welsh Region, and the only substitute source (Vyrnwy aqueduct) belongs to North West Water. Although a cross-connection already exists between the Vyrnwy aqueduct and the Severn Trent mains (at nearby Peckforton), no water is transferred through it.

If this all occurred in a single Water Company/NRA Region (eg. North West), the conjunctive use solution would be to:

i) provide a bulk supply of 5 Ml/d of Vyrnwy water instead of the 5 Ml/d from Tower Wood boreholes.

ii) in normal years, abstract no water from Tower Wood boreholes. Instead use North West Water's Dee abstractions to make up the difference. Here there is licensed but, as yet, unused water. Much more than 5 Ml/d is available for many years to come.

iii) allow the groundwater levels to recover naturally, or more rapidly by moderate artificial recharge from the Vyrnwy aqueduct (by gravity). The baseflows of the Aldford Brook (to the Dee) would be gradually restored, as the groundwater levels recovered.

iv) in the severe drought years, the NRA Welsh Region would be trying to conserve storage in Celyn and Brenig. At such times the boreholes could be pumped at high rates (eg. 20 Ml/d) for up to six months, into either the Vyrnwy Aqueduct or the Golborne Brook. After the drought, they would be rested to recover in time for the next major drought event.

Use of underground storage at Tower Wood would then become similar to that of Llyn Brenig - a reserve storage required only in severe drought years. The actual marginal costs of producing potable water at Huntington, Vyrnwy or Tower Wood are probably not greatly different. An intervention by NRA is needed to propose that, ideally, the licence should be modified to reflect this occasional high use. Following this, the boreholes and their licences could transfer from Severn Trent to North West Water (or NRA Welsh Region). Conjunctive use with the Dee and Vyrnwy sources could then follow. The 5 Ml/d loss to Severn Trent would need to be made good through a bulk supply agreement with North West Water via the Vyrnwy aqueduct.

In resources terms, this should restore the 5 Ml/d to the baseflows of the Aldford Brook (equivalent to a 5 Ml/d increase in Dee yield). It would also create at least 5,000 Ml (58 cumec-days) of usable underground storage in a severe 18-month drought.

OPTION 4: Transfers into the Dee Catchment

Possibilities for transfers into the Dee catchment, to improve yields or reliability, may be either continuous or 'drought only' options. Only a few realistic options have been identified in this study as worthy of further consideration. This is because of natural topographical boundaries, and the fact that the Clwyd and Aled (to the north) are also augmented river systems.

Option 4A: River Alyn

Due to the presence of swallow holes in the Carboniferous limestone, low and medium flows of the Upper Alyn, upstream of Rhydymwyn, sink into the river bed. Consequently, no natural flow passes across these "swallow holes" to the Lower Alyn for up 10 months per year. The natural situation is exacerbated by the presence of old mine drainage tunnels.

The options for conveying moderate amounts of the Upper Alyn flow across the leaky river bed were thoroughly investigated by the NRA in 1990. This study concluded that a 7 km gravity fed pipeline would be required. The additional flow into the Lower Dee in summer would be 3 to 5 Ml/d in a single summer drought. Care would need to be taken not to derogate from Dŵr Cymru's abstraction from the Bagillt tunnel outlet, by the Dee Estuary which is the eventual resurgence point of the swallow hole drainage.

Option 4B: Bagillt Tunnel to Alyn Transfer

A 13 km pumped main, with a static head of 140 metres, would be needed to re-pump excess Bagillt tunnel outflow back into the river Alyn at Mold. Up to 20 Ml/d could be transferred even in dry summers, without derogating from Dŵr Cymru's abstraction at the Bagillt tunnel outlet.

Option 4C: Llangollen Canal

The canal takes water from the River Dee at Llangollen. There are several points where moderate quantities of water (up to 5 Ml/d) could be discharged back into the Lower Dee tributaries from the Shropshire Union Canal. For example:

3 km NE of Whitchurch	: into Wych/Worthenbury Brook
2 km NE of Tattenhall	: into Golborne Brook, a tributary of Aldford Brook (new pipeline)
3 km SE of Chester	: into Caldy Brook at Christleton
At Chester	: upstream of Chester Weir
	: downstream of Chester Weir (existing locks)

Continuous discharges could be counted as part of river regulation releases, or residual flows to the estuary. However, they would need to be supported by inputs to the canal system from outside the Dee catchment. This support could come through:

* Redirecting Barnhurst STW from the River Severn.
* Use of 40 Ml/day of Birmingham Groundwater - this would require modifications to the canal to ensure the ability to carry this quantity of water.

Sources used to regulate the Severn could also provide water for the canal system in drought events if the Dee and Severn sources were operated conjunctively. There may also be other sources of occasional or continuous input, but none have been identified in the present study.

Option 4D: Afon Conwy

The catchment boundary at the north end of the Afon Gelyn (a tributary of Llyn Celyn) would allow a pumped, or gravity diversion, from the upper reaches of the Afon Conwy. However, the recent construction of a fish pass to open this reach of the Afon Conwy to migratory fish limits a river transfer to emergency use only. It would assist refill of Llyn Celyn in December to March of very dry winters. A 4 km long pipeline/catchwater might transfer 1,500 Ml (17 cumec-days) in such an event.

Option 4E: Llyn Conwy (Dŵr Cymru)

Llyn Conwy, a small direct supply reservoir operated by Dŵr Cymru, could be used to transfer water by gravity into the Gelyn tributary of Llyn Celyn. This relies on Dŵr Cymru linking this distribution system, which is outside the Dee catchment, with the Alwen supply. A 4 km long pipeline might transfer 1,500 to 2,000 Ml per year (17 to 23 cumec-days) on a continuous basis. There would be negligible benefit to overall Dee yields as the extra input from Llyn Conwy would be balanced by a greater abstraction at Alwen. However, the greater abstraction at Alwen might marginally help in reducing frequencies of overflows at Alwen, and pH variation in the Afon Alwen.

Option 4F: Llyn Trawsfynydd (Nuclear Electric)

Llyn Trawsfynydd, to the west of the Dee catchment, has a storage of 33,000 Ml (382 cumec-days). This is around 25% of the capacity of Llyn Celyn and Llyn Brenig combined. Since the decommissioning of Trawsfynydd nuclear power station, it is no longer used as a source of cooling water. It continues, however, as the source of water for Maentwrog Hydro-power station (30 MW maximum capacity).

To convey water from Llyn Trawsfynydd to the Llyn Celyn catchment area, a 12 km pipeline with a static lift of 203 metres would be required. This would discharge into Llyn Tryweryn, a small natural lake at the head of the Upper Tryweryn tributary.

It would be pointless, economically, to consider operating such a transfer, except in the second summer of 18-month droughts (eg 1934 and 1976). The storage in the Dee regulating reservoirs would then be well below what is required. Storage in Trawsfynydd for transferring to Llyn Celyn could only occur with the agreement of Nuclear Electric. This "reserve" would result in the loss of power generation income, and this would need to be compensated. This would be additional to the pumping costs, making the scheme very expensive.

This option should be costed in more detail, but in reality it is likely to be a yardstick against which to compare other alternatives.

OPTION 5: Assisted Refill Of Major Reservoirs

Options considered include assisted refill of Alwen Reservoir, Llyn Brenig, Llyn Celyn and Lake Vyrnwy (because of its combined use with Dee abstractions by North West Water). None of these reservoirs will refill in dry winters such as 1933/4 and 1975/6.

Assisted refill of Llyn Tegid and Clywedog Reservoir (River Severn) is not considered, as both will refill even in the driest winters this century.

Option 5A: Assisted Refill of Alwen Reservoir

5A1: Existing catchwater at Hafod-y-Llan Isaf

There is already a small existing catchwater entering close to the north end of the dam.

5A2: Pumping from Aled Isaf

This option is described as part of Option 2. Up to 1,500 Ml (17 cumec-days) could be transferred, even in a dry winter.

5A3: From existing Brenig Stage II refill option (Llanfihangel)

A 12 km pipeline, with a static lift of 104 metres, would be needed. It would transfer water from Llanfihangel/Derwydd on the River Dee to Alwen Reservoir. An existing, but unused, licence is available to enable this. A 225 Ml/d pump could produce enhanced refill of 2,700 Ml (31 cumec-days) in December to April of the driest winter.

Note: the licensed but unused pump refill option from Maerdy to Alwen would produce more water than was needed to refill Alwen Reservoir in the 1933/34 winter.

5A4: Releases from storage in Llyn Alwen

Llyn Alwen is a small privately owned lake which has SSSI status. Situated at the head of the Alwen Reservoir catchment, it naturally overflows into the reservoir. In 18-month droughts, the storage below overflow level (not yet assessed) could be pumped or released into either Alwen Reservoir or (through a diversion) into Llyn Aled.

Option 5B: Assisted Refill of Llyn Brenig

5B1: From Alwen Reservoir (link main)

The link main referred to in Option 2 would allow surplus water from Alwen inflow (natural, or from Aled Isaf) to be transferred to Llyn Brenig . This would help Llyn Brenig to refill after a major drawdown.

5B2: From Llyn Brân

Llyn Brân, with a capacity of some 200 Ml (2.3 cumec-days), lies at the head of the Llyn Brenig catchment, and overflows into Llyn Brenig. Until recently it was used as a direct supply reservoir by Dŵr Cymru (1 Ml/d to Denbigh), and was 18-month critical.

Dŵr Cymru now propose to use it for supplementary discharges (when necessary) to the Clwyd augmentation scheme or the Aled Regulation scheme. Both are single season critical. This is a sensible and flexible use of this storage.

There may be some storage left in Llyn Aled at the end of an 18-month drought, which could be released to Llyn Brenig as a 'last resort' action. This may pose a risk through fish transfers.

5B3: from existing Brenig Stage II refill options (Llanfihangel, Maerdy, Corwen)
An 8 km pipeline with a static lift of 117 metres would be needed. This would allow the transfer of water from Llanfihangel/Derwydd on the River Dee to Brenig Reservoir, under the existing unused licence. A 225 Ml/d pump could produce enhanced refill of 2,700 Ml (31 cumec-days) in December to April of the driest winter.

To transfer water from Maerdy to Llyn Brenig (existing unused licence), and from Llanfihangel, a 17 km pipeline with static lift of 194 metres (in two stages) would be required. 10,000 Ml (120 cumec-days) of enhanced refill to Llyn Brenig could be provided in December to April of the driest winter.

To transfer water from Corwen (R Dee) to Maerdy (existing unused licence), and from Maerdy to Derwydd, and from Derwydd to Llyn Brenig, a 24 km long pipeline with static lift of 245 metres (in three stages) would be required. 41,000 Ml (470 cumec-days) of enhanced refill to Llyn Brenig could be provided in December to April of the driest winter.

Some compulsory land purchase powers for parts of the pipeline route have lapsed. The licences, for transfer of water only, are held by the NRA.

5B4: from Llyn Celyn
Excess water in Llyn Celyn could be conveyed via a 20 km pipeline to Alwen Reservoir in two ways. The first would draw directly from the reservoir and involve a static lift of 70 metres. The second would take water from downstream of the stilling basin at Llyn Celyn. The static head here would be about 120 metres. Option 5B1 would then allow the water to be pumped into Llyn Brenig.

Spare water from Llyn Celyn for transfer to Alwen and Brenig would not be available in dry winters such as 1933/34. Even with pumping from Llyn Tegid (Option 5C4), there is insufficient water to refill Llyn Celyn in the 1933/34 winter.

A Celyn/Alwen/Brenig link would normally be used only in winters, after severe 18-month droughts (eg. 1934/35, 1935/36). There would then be spare "overflow" water from Celyn without the need for pumping from Llyn Tegid.

Such a link would cross the Afon Ceirw. However, no proposals are made for abstraction from the Ceirw as it is the largest natural spawning tributary in the Alwen catchment.

This link could also be used to discharge water from Llyn Brenig to Alwen Reservoir to Llyn Celyn. In this mode it could be used to:

a) transfer water from Llyn Brenig to Bala Sluice outflow during severe droughts. This would avoid the constraint which requires a minimum 1:2 ratio of regulated flows at the Dee/Alwen confluence. This in turn would allow Celyn to be used more intensively than at present in the first summer of 18-month droughts. It could also lessen the drawdown, and refill problems, at Brenig.
b) transfer of excess water (potential overflows) of low pH water from Alwen Reservoir to Llyn Celyn, for power generation, when it was not needed for Llyn Brenig refill.

The environmental impacts of such a major scheme need to be carefully assessed.

Option 5C: Assisted Refill of Llyn Celyn

5C1: Existing catchwater (Hesgin)

This catchwater was constructed under the Liverpool Corporation Act 1957; it commands a catchment of some 11 km^2 and increases the average runoff into Llyn Celyn by around 8%.

5C2: Afon Erwent Catchwater

Powers were obtained in the Liverpool Corporation Act 1957 (Work No 3) for a 6.5 km long catchwater. This would run from the Afon Erwent to the Nant Aberderfel, which is a south bank tributary of Llyn Celyn. The catchwater would intercept several other streams. The total catchment area of around 8.3km^2 could, if similar to the Hesgin, increase the Llyn Celyn annual inflow by around 6%.

Shorter catchwaters back from the Aberderfel could be considered as follows:

Table 9.

To	Length (km)	Extra Catchment (km^2)	% increase in Llyn Celyn inflow.
Nant-Hir	0.3	1.6	1.2
Llafar	2.0	5.4	3.9
Afon Dylo	3.2	6.7	4.9
Erwent	6.5	8.3	6.0

A 1% increase in Llyn Celyn inflow would give an additional inflow of around 330 Ml (4 cumec-days) in October 1933 to March 1934 inclusive.

The fisheries officer has reservations about transfers from these streams, which are important spawning areas. The decision about why the catchwater was not constructed when the scheme was originally promoted is not known.

5C3: Afon Conwy Catchwater/Llyn Conwy

These are transfers from outside the Dee catchment area and they have already been identified as Options 4D and 4E.

5C4: Llyn Trawsfynydd

This is a possible transfer from outside the Dee catchment area and it has already been identified as Option 4F.

5C5: Llyn Arenig Fawr

Llyn Arenig Fawr overflows into Nant Aberderfel and into Llyn Celyn. It is used as a direct supply reservoir by Dŵr Cymru for public supply in the Bala area. All water abstracted (except for any consumptive use) returns to Llyn Tegid or the Dee catchment. In recent years, leakage control has significantly reduced the draw-off. The reservoir now only falls below spillway level in severe summer droughts. It should always recover and overflow into Llyn Celyn at present demands, even in the driest winter.

With modifications to the draw-off arrangements, the unused dead storage in Llyn Arenig Fawr could

be discharged into Llyn Celyn. This could be useful in the second summer of an 18-month drought, as long as the direct supply abstraction and the fishery was adequately protected. However, Dŵr Cymru may wish to reserve this option as one of their contributions towards "Stage 2" Drought General Directions.

5C6: Llyn Arenig Fach and Llyn Tryweryn

Both these natural lakes lie within the Llyn Celyn catchment area, and always naturally overflow. In the second summer of an 18-month drought, some storage within these could be released (or pumped) into Llyn Celyn.

The stage - storage relationships have not been identified yet, nor have quantities been estimated. However, a 1 metre drawdown in either would produce around 100 Ml (1.16 cumec-days) from either lake.

5C7: Afon Mynach

A gravity catchwater from the Afon Mynach into Llyn Celyn would not be very practical (the levels being such as to limit the contributing catchment area). However, it could be practical to reduce the Celyn compensation water as an optional conservation measure. This would only occur when the flow in the Mynach was substantial. This is currently the case with Vyrnwy Reservoir and the Hirnant tributary.

The Afon Mynach is the most important spawning tributary of the Afon Tryweryn. However, the Tryweryn between the Mynach confluence and the Fish Trap downstream of Llyn Celyn attracts few spawning fish. No interference or diversion of the Mynach winter flows would be contemplated. A pump and 3 km pipeline between the confluence and the stilling basin, with a 50-metre static lift, would 'recirculate' the Llyn Celyn winter compensation water of 0.37 cumecs. This could result in a saving of some 1,300 Ml (15 cumec-days) in January to March of 1934.

5C8: Pumped Refill from Llyn Tegid

Pumped refill of Llyn Celyn from Llyn Tegid is worthy of serious consideration, as

i) pumping could take place whenever there was excess water (above specified control rules) in the lake at any time of year - not just in winter.

ii) any water released from Llyn Celyn that was solely for the benefit of fisheries or recreation (rafting, canoeing), but was not required for regulation (downstream of Bala Sluices), could be returned to Llyn Celyn, rather than wasted.

iii) pumping from a lake is less likely to cause disturbance to the environment than pumping from a river (eg. Brenig refill from Corwen/Maerdy/Llanfihangel - Option 5B3).

In all the following cases, the pipeline would be approximately nine kilometres long. Two pipeline routes could be considered. The first follows the route of the abandoned railway track between Bala and Celyn. This route is generally clear of obstructions and provides a smooth gradient. However, the track is too narrow to permit effective pipe installation. It also crosses the river at two locations, and the embanked sections would have to be removed to install the pipe. Due to these difficulties it is likely that a direct cross country route would be preferable. This would result in a pumping head of around 150 metres to raise the water 138 metres from Llyn Tegid into Llyn Celyn.

Option 5C8a would consist only of recirculating Llyn Celyn compensation water (0.37 cumecs) from Llyn Tegid to the Llyn Celyn stilling pool (a static lift of 88 metres). This would reduce Llyn

Celyn drawdown by 3,900 Ml (45 cumec-days) in December to March 1934, if the operation was allowed throughout this period.

Other achievable refill volumes, in December to March of 1933/34, have been estimated for different pumped transfer rates of 1 to 6 cumecs from Llyn Tegid into Llyn Celyn. These are based on a daily sequence for Llyn Tegid inflows, with an upper control line in Llyn Tegid of 1,700 Ml (20 cumec-days). They also assume no pumping took place when the storage was below this control line. Pumpable figures for December 1933 to March 1934 (which include re-pumping of Llyn Celyn compensation water) are shown below, with Option references.

Table 10.

Option Reference	Pump Output (cumecs)	Pumpable Volume cumec-days	Pumpable Volume Ml
5C8bw	1.0	49	4200
5C8cw	2.0	97	8400
5C8dw	3.0	145	12500
5C8ew	4.0	193	16700
5C8fw	5.0	237	20500
5C8gw	6.0	271	23400

Note that, at full yield of 13.5 cumecs maintained flow in the 1933/34 drought, the additional inflow needed to refill Llyn Celyn by 1st April 1934 would be 50,100 Ml (580 cumec-days). So, even with a 6 cumecs pump, Celyn would be 26,800 Ml (310 cumec-days) below the required volume on 1st April 1934.

However, the existence of such pump transfers would enable Celyn to be topped up whenever there was excess water at Llyn Tegid in 1933 and 1934. If this is considered, the pumpable volumes between 1st July 1933 and 1st July 1934 would have been:

Table 11.

Option Reference	Pump Output (cumecs)	Pumpable Volume cumec-days	Pumpable Volume Ml
5C8by	1.0	91	7900
5C8cy	2.0	179	15500
5C8dy	3.0	259	22400
5C8ey	4.0	334	28900
5C8fy	5.0	400	34600
5C8gy	6.0	454	39200

These substantial transfers would have greatly reduced the risk of Stage 2 Drought General Directions. The improved storage in Llyn Celyn would also have reduced the "second summer" demand on Llyn Brenig. This would reduce drawdown in Brenig and ensure refill within five years.

If the extra input was ascribed to yield alone, then each 400 Ml (4.6 cumec days) of pumpable volume would produce an additional licensable yield of roughly 1 Ml/d, ie:

a 1 cumec pump would produce 19 Ml/d of yield
a 3 cumec pump would produce 56 Ml/d of yield
a 6 cumec pump would produce 113 Ml/d of yield

The environmental impacts of such a major scheme need to be carefully assessed.

Option 5V: Assisted Refill of Vyrnwy Reservoir

5V1: Existing catchwaters and water bank

There are two existing catchwater diversions into Vyrnwy - the Marchnant and the Cownwy. Neither has a residual flow condition; all the flow up to the tunnel capacity can be diverted into Vyrnwy.

The normal Vyrnwy compensation water is 45 Ml/d (from 93km^2 catchment area). This is comparable with the Llyn Celyn winter compensation water of 32 Ml/d from 60km^2. However, the Llyn Celyn summer compensation water is twice this amount (64 Ml/d).

The Vyrnwy compensation water can be reduced to 25 Ml/d whenever the flow in the Cownwy is more than 20 Ml/d ; the water 'saved' is added to a 'water bank'. The water bank also receives an allocation of 725 Ml on the 1st of each month from March to October inclusive. Water is 'lost' from the water bank if:

* the reservoir effectively spills (above flood control curve) or
* if releases are made for regulation or fisheries at the request of Severn Trent NRA.

In 1995 regulation releases of around 3400 Ml (39.4 cumec-days) had been made by Severn Trent NRA from the end of June to the end of October. As a result on November 1st 1995 the water bank stood at 1000 Ml (11.6 cumec-days). By the end of the regulation season in November the water bank had fallen to 700 Ml (8.1 cumec-days).

It is not clear from the rules what happens if Vyrnwy fails to refill (as in 1933/34, 1975/76 and probably some other occasions). The rules say that any unused water bank from the first summer may be carried over to the second. The NRA National Strategy (Hydrological Modelling, Supplementary Report No 5) is based on modelling. It assumes no carry-over, and only seven sets of 725 Ml allocations (1st March to 1st September).

A volume of 1500 to 2000 Ml (17.4 to 23.1 cumec-days) is a typical water bank value at the end of a single year drought such as 1995. This could be 'switched' from NRA Severn Trent use to NRA Welsh use (if needed to reduce Llangollen canal abstractions in a second summer - Option 1A). The effect could be similar to several options for assisted refill of Llyn Celyn or Llyn Brenig. If the water bank is not needed in the second year for the Severn, it could be used to relieve demands on the Dee.

5V2: Pumping from Meifod

For comparison with the option of re-pumping Llyn Celyn compensation water from Llyn Tegid, an option for re-pumping Vyrnwy basic compensation water from Meifod has been assessed. This assumes that only the compensation water is available. In practice additional water may be available.

A 25 km pipeline, with a static lift of 145 metres would be required. In December 1933 to March 1934, this would reduce the Vyrnwy drawdown by 4200 Ml (49 cumec-days). This 'saved' water would presumably go into the Severn Trent NRA water bank.

This option does not compare favourably with the Llyn Tegid to Llyn Celyn stilling pool recirculation (Option 5C8a). This would reduce Celyn drawdown by 3900 Ml (45 cumec-days) for a static lift of only 88 metres, and a very short pipeline length.

5V3: Pumping from the Banwy

Drawing water from the Banwy and pumping over into the Vyrnwy at Dolanog, would require 15 km of mains, two pumping stations and 81 metres total static lift. The savings would be the same as Option 5V2. Similarly this does not compare favourably with the Llyn Tegid/Llyn Celyn option; the static lift is less, but the Banwy Option pipeline is twice as long.

5V4: Other Schemes to enhance the Vyrnwy water bank

From a Welsh Region NRA viewpoint, pumped refill of the Vyrnwy does not appear to outweigh the costs and benefits of similar schemes in the Dee catchment. However, it is recommended that such schemes are assessed by NRA Severn Trent Region in relation to possible post 2021 Severn to Thames transfers.

This is due to the need to supplement Thames river flows because 1 in 50 year 'Level 3' restrictions are required or contemplated. Of the three occasions to date in the 1920 to 1992 records, two occur in the second summer of an 18-month drought sequence (1934, 1976). The other occurs in 1921.

Vyrnwy significantly fails to refill in both 1933/34 and 1975/76. Pumped refill (from Meifod or Banwy) by Severn Trent NRA could overcome this and create a much larger 'water bank' by the start of the second summer. The Vyrnwy yield would be needed (currently limited in practice by trunk mains capacity to 190 to 215 Ml/d) to create a larger 'water bank'.

NRA Severn Trent are planning to investigate these options by 1998.

OPTION 6: Enhanced Reservoir Capacity

6.1: Llyn Celyn

The option to raise Llyn Celyn was published in "Water for Welsh Region". This had originated from work undertaken by the consulting engineers Binnie and Partners. They estimated that ".. raising the dam crest by 1.5 metres will enable the reservoir ... to increase yield by between 20 and 25 Ml/day". This increase in storage and yield was applied to the results of the Surface Water Yield R & D Project. The results suggest that the frequency of restrictions to customers would be increased from one in five years on average to less than one in four years. The maximum drawdown period would increase from the current eight years to ten years. This is the number of years taken, during the worst recorded drought, for the reservoir to again reach a full state.

As a result, an increase in storage would give a moderate increase in licensable water, but the reliability of the new and existing abstractions would be substantially reduced. In this context the NRA could not issue licences for this increased yield.

The flood mitigation uses of Llyn Celyn requires storage capacity to be made available throughout the flood season. Consequently, the reservoir could never be allowed to fill, thereby removing much of the benefit of raising the dam crest.

The potential benefits of raising Llyn Celyn dam are therefore outweighed by the disadvantages. This option is therefore considered not viable, and is dismissed from the Regional Strategy and this report.

OPTION 7: Re-Locating Effluent Discharges

7A: Chester Sewage Works

Chester Sewage Works effluent (27 Ml/d approximately) is discharged approximately two kilometres downstream of Chester Weir. The works are owned and operated by Dŵr Cymru.

Under the current Dee General Directions, the Chester STW discharge is not considered as part of the design residual flow (4.2 cumecs, 373 Ml/d) to the estuary. However, under Drought General Directions the design residual flow reverts to 'natural' low flows of 2.2 to 3 cumecs. These 'low' flows into the head of the tideway include the Chester Sewage Works effluent.

This is an anomaly that needs to be rectified. If the effluent can be counted as part of residual flow under Drought General Directions, why not under Normal General Directions? If it is not acceptable under Normal General Directions, why is it allowed under Drought General Directions?

NRA policy (nationally and regionally) is to encourage discharge of effluent as close to the point of abstraction as possible, for potential re-abstraction. 27 Ml/d is an important resource, in the context of the Dee. An option to pump this effluent to upstream of Chester Weir would (depending upon where the point of discharge was) require a pipeline not less than two kilometres long. The static lift would only be around three metres. Pumping need only take place as a conservation measure, in dry years, rather than permanently. However, such a proposal would be subject to water quality considerations, fisheries impact, aesthetics, and public health issues.

7B: River Alyn

The River Alyn, downstream of Rhydymwyn, already receives a certain quantity of sewage effluent derived from the Alwen and Dee sources, operated by Dŵr Cymru.

Effluent currently discharged to Queensferry Sewage Works could be re-routed into the Alyn to enhance low flows in the Dee. The necessary transfer works and volumes have not been quantified.

A pipeline over nine kilometres would be required. The issue of dilution of the discharge in the Alyn is problematic; dilution problems are already known to exist.

OPTION 8: Emergency Measures

8A: Drawdown of lakes/reservoirs below normal lowest level in 2nd Summer, 18-month drought.

The following options are seen as short term emergency measures which could only be considered under very extreme conditions. By their very nature, they are likely to have environmental impacts. As a result they should be carefully considered. As emergency measures they are also likely to be required within a short timescale. It is therefore important that their impact is considered sooner rather than later.

The need for these emergency measures may be overcome through the timely development of other resources schemes. The options previously covered in this report should be assessed to help mitigate the need for emergency measures. Nevertheless, it is still prudent to identify options that would help provide water at times of severe shortages.

Options for emergency drawdown of Llyn Arenig Fawr, Llyn Tryweryn, and Llyn Arenig Fach have been identified in refill options for Llyn Celyn (Options 5C5 and 5C6).

Options for emergency drawdown of Llyn Alwen (Option 5A4) and Llyn Brân (Option 5B2) have been identified for Alwen Reservoir and Llyn Brenig.

Any reserves of dead storage in Alwen Reservoir would be used by Dŵr Cymru during a second drought summer by introduction of pumping below normal draw-off level.

The Cilcain and Brithdir reservoirs are owned by Dŵr Cymru but currently used only as standby sources. They have a respective capacity of 130 Ml (1.5 cumec-days), and 20 Ml (0.2 cumec-days), and discharge to the Upper Alyn. They could not enhance the Lower Dee summer flows unless the Alyn Transfer Scheme (Option 4A) was in place.

Pen-y-Felin Fawr reservoir with a capacity of 20 Ml (0.2 cumec-days), is so small that it would make no difference to overall Dee regulation yields or security of supply.

The small upland reservoirs owned by Wrexham Water would, like Alwen, be used by the water company in the second drought summer, to relieve demands on the Dee. In this way the company can meet the requirements of the Dee General Directions to reduce their River Dee abstractions.

Llyn Tegid has a sufficient surface area and storage to allow it to be considered as an emergency source. Pumping from the lake could be used as an emergency measure at the end of the second summer of a drought worse than 1933/34. The pumping period would likely occur between September and November.

Each one metre drawdown below cill level of the lake discharge gate (159 metres AOD) would produce 3900 Ml (45 cumec-days) of storage. This would be sufficient to sustain almost eight days of releases at an abstraction rate of six cumecs. The shallow sloping shore line at the north east end of Llyn Tegid provides difficulties for abstraction. To enable a reasonable drawdown, the abstraction point would need to be sited 400 metres out into the lake. This rules out pumping from the lake margins due to cost and environmental disruption.

The most practical and cost-effective option is the use of floating pontoons equipped with suitable pumps and delivery lines to the River Dee channel. Up to six "land drainage" low head pumps could be arranged on pontoons with delivery pipelines leading to stoplogs fitted across the B4391 road

bridge piers. A maximum drawdown below the discharge gate sill of two metres only is contemplated. At maximum drawdown this would result in a total pumping head of seven metres. The impact on reduced water levels on Llyn Tegid and the lake margins would have to be fully investigated.

The need for emergency "over-pumping" is only likely to occur approximately once in 100 years. Once used the pumping installation would not be needed for a considerable time. The design of such a scheme would therefore need to take account of the temporary nature of the works. The potential to scrap or resell parts after the emergency has ended should be considered.

Similar over-pumping schemes are already written into abstraction licences for other fast-filling North Wales reservoirs (eg Cwellyn). When the weather breaks, the storage deficit would refill within days rather than weeks. This would therefore occur before the spawning of protected fish, such as the gwyniad and arctic char, commenced.

8B: Reduction of Residual Flows to Estuary

8B1: Design residual flows in dry winters

During winter, Dŵr Cymru, North West Water and Wrexham Water are encouraged to take from the Dee, and rest their conjunctive use reservoirs (for example Alwen and Vyrnwy). During the winter of 1995/96 this has been carried out to good effect. Operation would be based on defined control rules.

During very dry winters such as 1933/34 and 1975/76, the Dee's natural flow s fall to levels where they must be supported. On these occasions Llyn Celyn or Llyn Brenig are used to ensure maintenance of the design residual flow of 4.2 cumecs at Chester Weir. These regulation releases can use very large quantities of water.

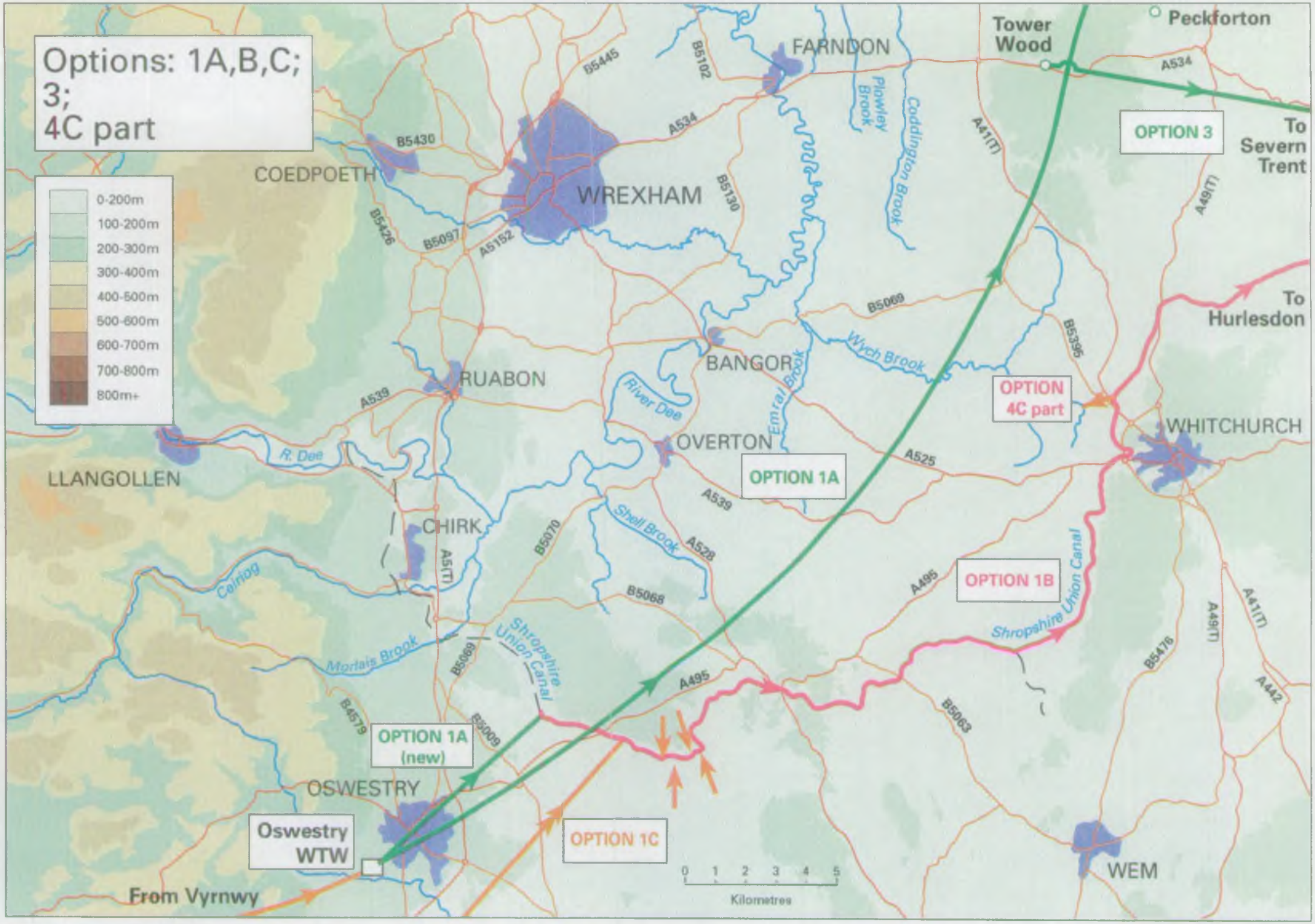
When Celyn, Brenig and Vyrnwy levels are recovering, and no significant numbers of migratory fish are moving up over Chester Weir, a temporary lower residual flow may be acceptable. This would help refill of the regulating reservoirs for the following summer, through reducing regulation releases. Any changes in the current operating rules need to be carefully considered.

8B2: Design residual flows in dry summers

Under Stage 1 of Drought General Directions, the flow over Chester Weir is allowed to revert to the natural flow from the whole Dee catchment area.

Under Stage 2, the flow is reduced to the natural flow from the uncontrolled catchment area.

The temporary cessation of discharges to the estuary could be considered as an emergency measure (this can happen on the Severn in extreme droughts). This would require a temporary blocking of Chester Weir, to avoid tidal reversals at spring tide. It could save around 170 Ml (2 cumec-days) for each day it was in operation.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700-800m
800m+
FARNDON
Tower Wood
Peckforton
OPTION 3
To Severn Trent
To Hurlesdon
COEDPOETH
WREXHAM
BANGOR
RUABON
OVERTON
OPTION 4C part
WHITCHURCH
OPTION 1A
LLANGOLLEN
CHIRK
OPTION 1B
OPTION 1A (new)
OSWESTRY
Oswestry WTW
OPTION 1C
From Vyrnwy
WEM
River Dee
R. Dee
Ceiriog
Morlais Brook
Shell Brook
Wych Brook
Emral Brook
Plowley Brook
Coddington Brook
Shropshire Union Canal
B5445
B5102
A534
B5430
B5426
B5097
A5152
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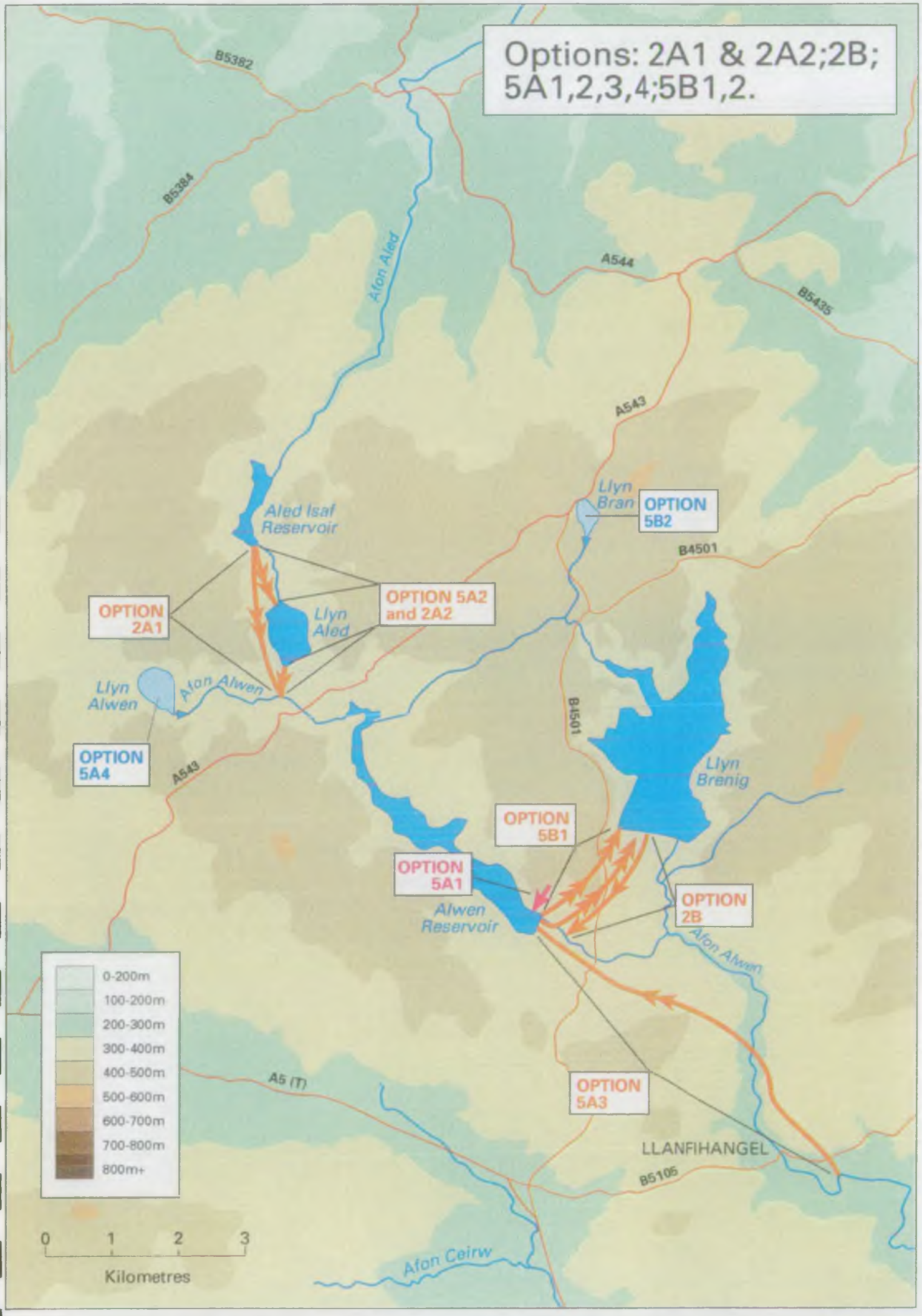
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Llyn Bran
OPTION 5B2
B4501
OPTION 2A1
OPTION 5A2 and 2A2
Llyn Aled
Llyn Alwen
Afon Alwen
OPTION 5A4
A543
B4501
Llyn Brenig
OPTION 5B1
OPTION 5A1
Alwen Reservoir
OPTION 2B
Afon Alwen
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100-200m
200-300m
300-400m
400-500m
500-600m
600-700m
700-800m
800m+
A5 (T)
OPTION 5A3
LLANFIHANGEL
B5105
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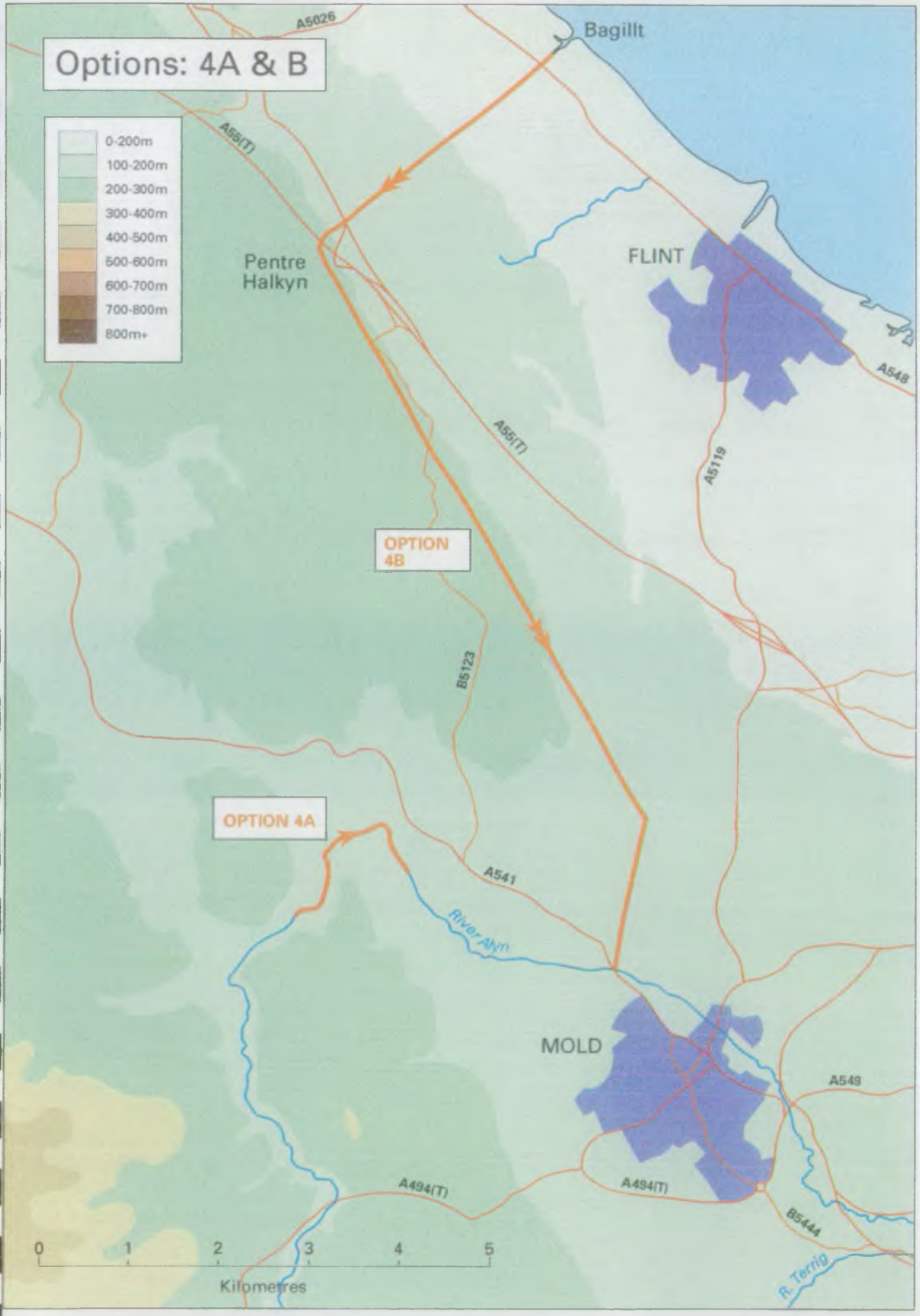
Kilometres
Afon Ceirw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Bagillt
A55(T)
Pentre Halkyn
FLINT
A548
A55(T)
A5119
OPTION 4B
B5123
OPTION 4A
A541
River Alyn
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A549
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R. Terrig
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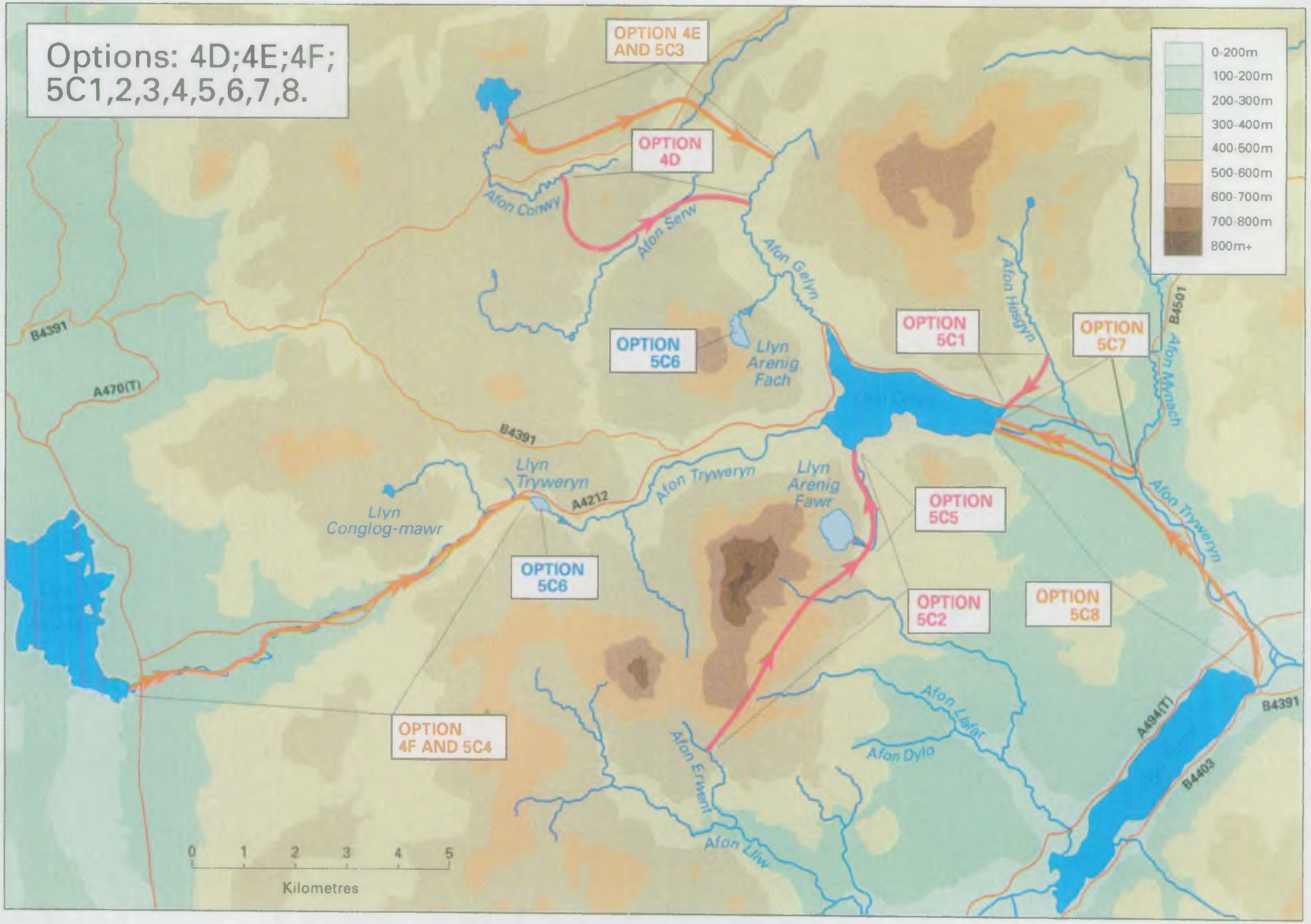
1
2
3
4
5
Kilometres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OPTION 4D
OPTION 5C6
OPTION 5C1
OPTION 5C7
OPTION 5C5
OPTION 5C2
OPTION 5C8
OPTION 5C6
OPTION 4F AND 5C4
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100-200m
200-300m
300-400m
400-500m
500-600m
600-700m
700-800m
800m+
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Afon Serw
Afon Gelyn
Afon Hesgyn
Afon Mynach
Llyn Arenig Fach
Llyn Arenig Fawr
Llyn Tryweryn
Afon Tryweryn
Llyn Conglog-mawr
Afon Ceiriog
Afon Llafar
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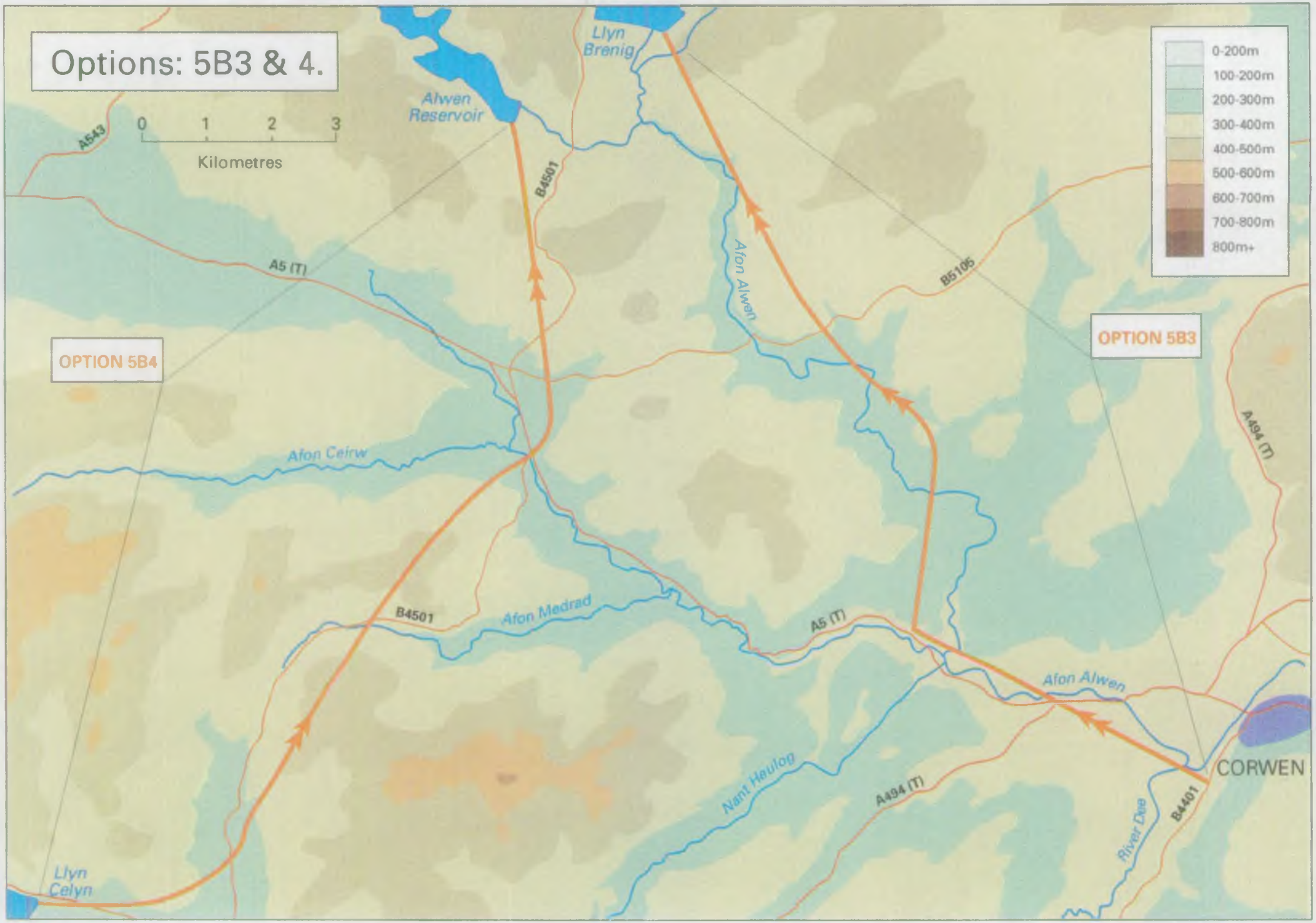
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100-200m
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300-400m
400-500m
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600-700m
700-800m
800m+
OPTION 5B4
OPTION 5B3
Alwen Reservoir
Llyn Brenig
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B4501
A5 (T)
Afon Alwen
B5105
Afon Ceirw
A494 (T)
B4501
Afon Medrad
A5 (T)
Afon Alwen
Nant Heulog
A494 (T)
River Dee
B4401
CORWEN
Llyn Celyn


Options: 5V1,2,3,4.
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100-200m
200-300m
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400-500m
500-600m
600-700m
700-800m
800m+
OPTION 5V1
OPTION 5V1
OPTION 5V2 & 5V4
OPTION 5V3
OPTION 5V4
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B4391
B4393
B4393
B4395
Afon Cownwy
Afon Efyrnwy
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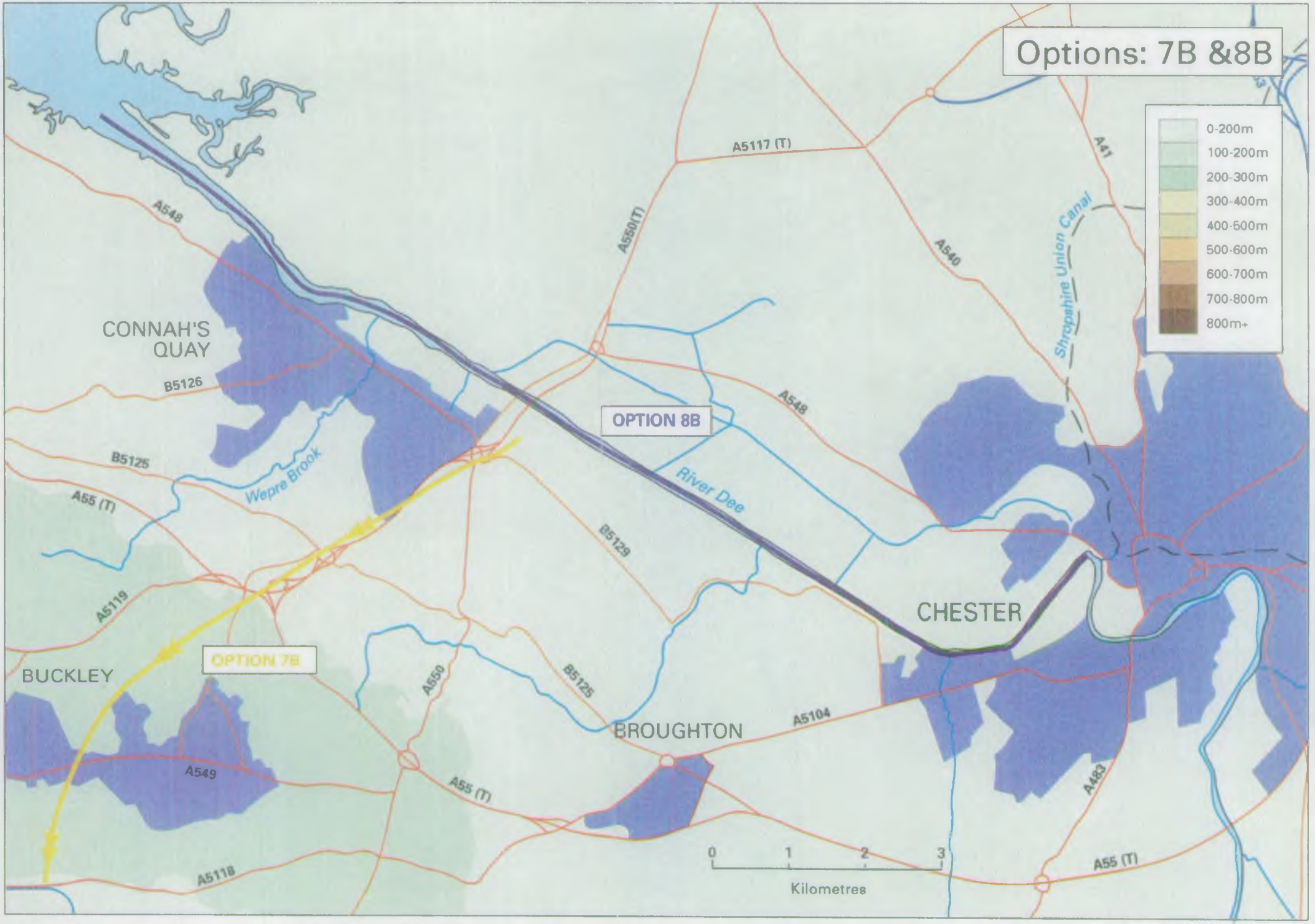
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200-300m
300-400m
400-500m
500-600m
600-700m
700-800m
800m+
A5117 (T)
A548
A550(T)
A540
A41
Shropshire Union Canal
CONNAH'S QUAY
B5126
OPTION 8B
A548
B5125
Wepre Brook
River Dee
A55 (T)
B5129
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CHESTER
OPTION 7B
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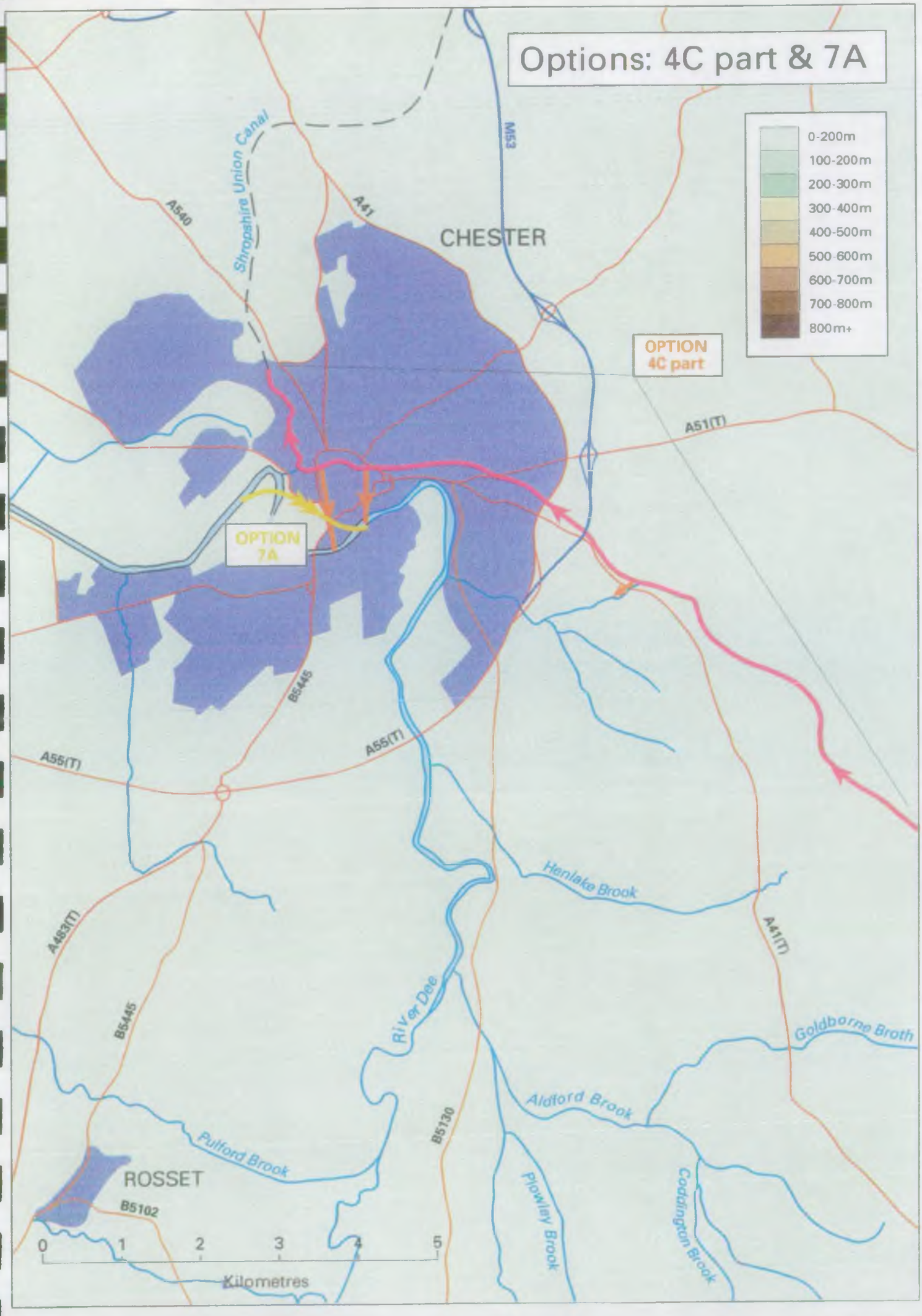
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300-400m
400-500m
500-600m
600-700m
700-800m
800m+
CHESTER
ROSSET
OPTION 4C part
OPTION 7A
M53
A41
A540
Shropshire Union Canal
A51(T)
A55(T)
A56(T)
A483(T)
B5445
B5130
B5102
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Henlake Brook
Aldford Brook
Pulford Brook
Plowley Brook
Coddington Brook
Goldborne Broth
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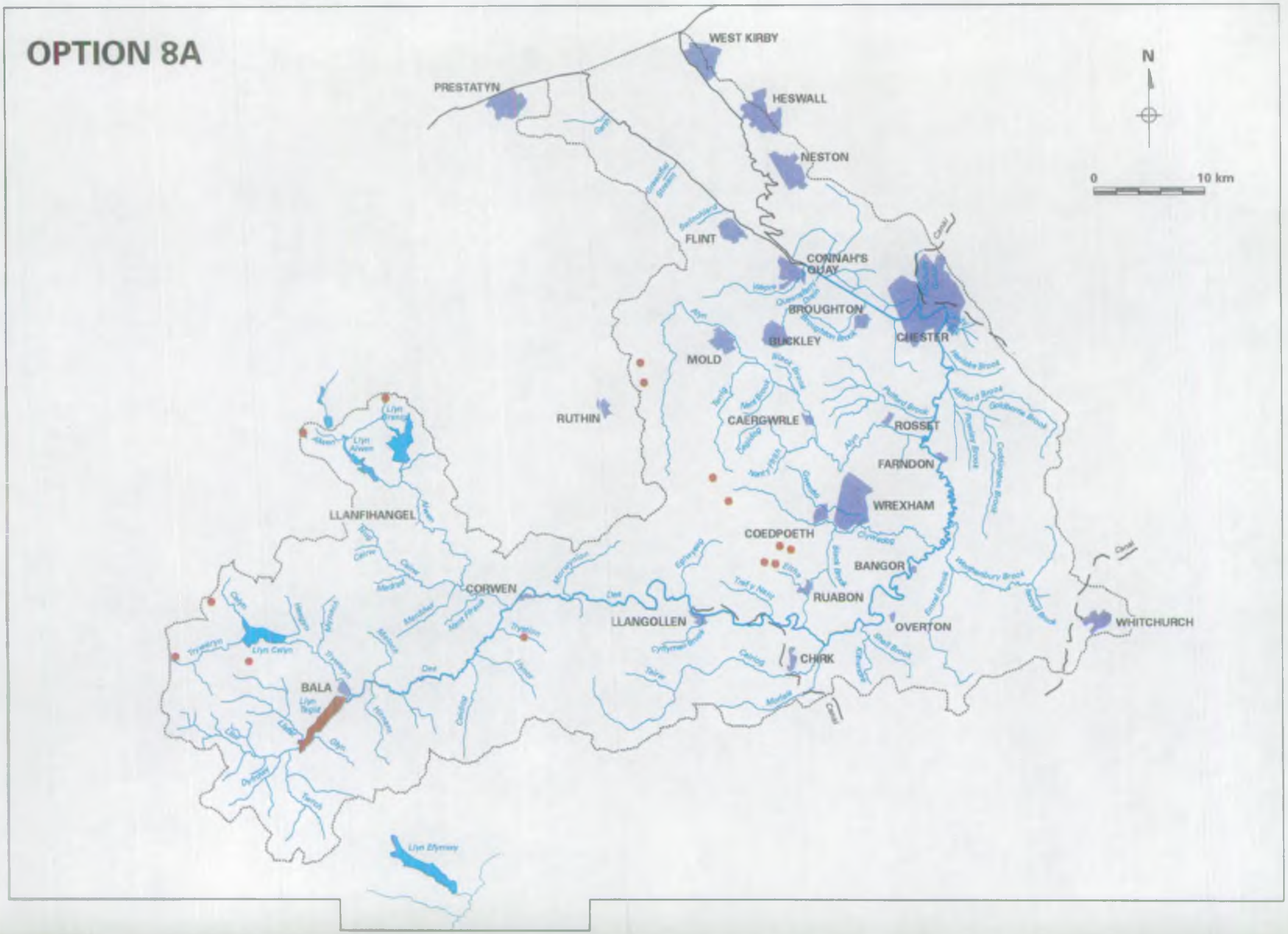
Kilometres

OPTION 8A


WEST KIRBY
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CAERGWRLE
ROSSET
FARNDON
WREXHAM
COEDPOETH
BANGOR
RUABON
CORWEN
LLANGOLLEN
OVERTON
WHITCHURCH
CHIRK
LLANFIHANGEL
BALA
Llyn Celyn
Llyn Efyrnwy
N
0
10 km

3. PRIORITISING OPTIONS, AND POSSIBLE SEQUENCE OF DEVELOPMENTS

3.1 Assumed Standards of Service (SOS)

3.1.1 The problem of future water resource management on the Dee is not simply related to matching yields and demands. As the demand rises the standards of service, in terms of the duration of reservoir drawdown, and frequency of reduced flows over Chester Weir, will deteriorate.

3.1.2 The following sequence of developments uses the same five year standards for maximum drawdown duration of surface water reservoirs as in North West Region. They also use the Severn Trent once in five years frequency for reductions in maintained river flows.

3.1.3 Where improved inflow to the Dee regulating reservoir storage in an 18-month drought has been identified (in Section 2), it is valued in "yield" terms. This gives a 1 Ml/d yield increase for 400 Ml (4.6 cumec-days) extra storage. This is the approximate slope of the yield storage relationship at the full yield maintained flow of 13.5 cumecs.

3.1.4 The only groundwater developments considered are the Bagillt tunnel to Alyn Transfer (Option 4B), and proposals for flexible use of the Sherwood sandstones at Tower Wood (Option 3).

3.2 Developments in Dee Regulation

The four figures used to demonstrate the following relationships can be found at the end of this sections.

3.2.1 **The Maintained Flow, Storage and Standards of Service Inter - Relationship.**
Figure 1. shows the inter-relationship between maintained flow (cumecs) on Y axis, and:

* Celyn /Brenig regulation storage (lower X-axis, in cumec-days).
* frequency of imposition of current "Stage 1" Drought General Directions (upper X-axis, in years).
* maximum drawdown period of Llyn Brenig (upper X-axis, in years).

3.2.2 **Current Situation (12.5 cumecs)**
At the current (1995) maintained flow of 12.5 cumecs (as shown in Figure 1.1) the maximum drawdown period is four years. The frequency of restrictions is once in 6.2 years. This is within the suggested standards of service.

3.2.3 **First Trigger: Five year maximum drawdown, when maintained flow reaches 12.7 cumecs.**
As the maintained flow rises, (see figure 1.2) the first standard of service to be transgressed will be the maximum drawdown period (of Llyn Brenig). This will start to exceed five years when the maintained flow rises to 12.7 cumecs. This is 0.2 cumecs (17.3 Ml/d) above the 1995 maintained flow.

3.2.3.1 There are three general solutions to meeting this standard of service:

a) enhance the refillability of Llyn Brenig (particularly in the period 1933-1937, and 1975-79).

b) "write off" 0.8 cumecs (69.1 Ml/d) of the remaining yield, already licensed but unused. Also, consider some 25,920 Ml (300 cumec-days) of the existing Brenig storage as an "emergency reserve".

c) consider some 25,920 Ml (300 cumec-days) of the existing Brenig storage as an "emergency reserve" against the unknown end-date of 18-month droughts. Also, create 69.1 Ml/d additional yield on the Dee by other means.

3.2.3.2 "Refillability" options under (a), are outlined in Options 5A to 5C. The only options that could probably provide water in sufficient quantities relate to pumped refill of Llyn Brenig, either from:

* Alwen/Aled reservoirs (Options 5B1 and 5A2)
* Llanfihangel/Maerdy/Corwen (Option 5B3)
* From Llyn Celyn (Option 5B4)

3.2.3.3 With option 5A2, a marginal increase in yield can be expected through conjunctive use (Options 2A1, 2A2, 2B)

3.2.3.4 "Writing Off" options under (b) can be costed for "buying out" 69.1 Ml/d of the currently unused part of the North West licence. This depends very much on North West Water's plans regarding future development of the Huntington Treatment Works. Although not in their 10-year AMP programme, drought related difficulties within their supply system might provide the incentive to upgrade the works to the current licence entitlement. Such actions would remove this option.

3.2.3.5 "Additional Yield" options under (c) would have to involve:

* pumped refill of Llyn Celyn (eg. by option 5C8gw or option 5C8ey), or
* smaller pumps with relocation/reuse of Chester Sewage Works effluent (option 7A), and/or
* pumping excess Bagillt tunnel outflow back into the Alyn near Mold (option 4B).

The "emergency reserve" in solutions (b) or (c) above could become an emergency reserve not only for the Dee, but also for the Aled, Clwyd, Severn and Thames, ie. a "National Strategy" reserve storage.

Recommendation 1:

If the proposed standard of service of a 5-year drawdown is adopted, the above options should be investigated in more detail (quantified and costed). They should be suitably ranked, considering in Options 5B1 and 5B2 the influence on conjunctive use operation with Alwen direct supply reservoir in 18-month droughts.

3.2.4 Second Trigger: Frequency of "Stage 1" Drought General Directions.

3.2.4.1 If a more relaxed standard of service for maximum duration of drawdown is accepted (eg. 10 years, as in the original Brenig Stage II yield calculations with pumped refill), then the next trigger to be transgressed could occur when the maintained flow reached 13 cumecs. This is 0.5 cumecs (43 Ml/d) above the 1995 maintained flow (figure 1.3). As with the first trigger, there are three general solutions to meeting this standard of service:

a) enhance the refillability of Llyn Brenig and Llyn Celyn (particularly in the period 1933-1942, and 1975-79).

b) "write off" 0.5 cumecs (43 Ml/d) of the remaining yield, already licensed but unused. Consider some 17300 Ml (200 cumec-days) of the existing Brenig storage

as a "National emergency reserve".

c) consider some 17300 Ml (200 cumec-days) of the existing Brenig storage as an "emergency reserve" against the unknown end-date of 18-month droughts. Create additional yield on the Dee by other means.

3.2.4.2 "Refillability" options under 3.2.4.1 (a) are outlined in Options 5A to 5C. Only two options are able to provide water in sufficient quantities:

* pumped refill of Llyn Brenig from Corwen/Maerdy/Llanfihangel (full option 5B3), and
* pumped refill of Llyn Celyn from Llyn Tegid (options under 5C8).

The latter is the "front runner" for the reasons outlined in the Options section.

3.2.4.3 "Writing Off" options under 3.2.4.1(b) can be costed in terms of "buying out" 43 Ml/d of the existing North West Water licence. This is currently believed to be 73 Ml/day ("Water, Nature's Precious Resource").

3.2.4.4 "Additional Yield" options under 3.2.4.1 (c) of this size would have to involve pumped refill of Llyn Celyn (eg. by option 5C8gw or option 5C8cy). It may also be just achievable by relocation/reuse of Chester Sewage Works effluent (option 7A) and pumping of Bagillt tunnel outflow back into the Alyn near Mold (option 4B).

Recommendation 2:

A standard of service of a 10-year draw down in Llyn Brenig may be acceptable. The trigger for further capital works would then become the failure to meet a 1 in 5 year frequency of not maintaining the prescribed flow. (This is currently Stage 1, Drought General Directions). The above options should be investigated in more detail (quantified and costed) and suitably ranked.

3.2.5 Small Incremental Additional Yields on the Dee

3.2.5.1 Recommendations 1 and 2 above cover all major schemes associated with Dee regulation. The benefits of additional works would be enjoyed (to a greater or lesser extent) by all the designated abstractors. Any such schemes involving pumping, or modifications of existing abstraction licences, could not reasonably be promoted (or operated) other than through Section 20 Operating Agreements initiated by NRA.

3.2.5.2 However, there are several options in Section 2 that could provide a separate and easily defined small input. This could "guarantee" additional licensed abstraction through a clearly identified and measured input of extra water into the Dee catchment (or Dee regulating reservoirs) in 18-month droughts. Many of these schemes could be developed by an individual abstractor. Note that such abstractions might need to be operated outside the Dee & Clwyd River Authority Act and General Directions.

3.2.5.3 Examples shown below in Table 12 suggest the volumes which could be transferred in the design drought (in Ml). The table also shows the additional yield (to nearest Ml/d) which could be guaranteed. The organisations which would have to be operationally involved in such a scheme are also shown.

Table 12.

Option	Description	Storage Volume (Ml)	Yield (Ml/d)	Possible Operator	Other Associated Options
2A1, 2A2	Link Mains, Aled to Alwen	1500	4	Dŵr Cymru	
4A	Upper Alyn transfer	n/a	3 to 5	anyone	
4D	Afon Conwy	1500	4	Dŵr Cymru	and 5C3
4E	Llyn Conwy	1500	4	Dŵr Cymru	and 5C3
5A2, 5A3, 5A4	Alwen Refill	4200+	-	Dŵr Cymru	
5B2	Llyn Brân	200	0.5	Dŵr Cymru	
5C2	Erwent Catchwater	400 to 2,000	1 to 5	Dŵr Cymru	
5C5	Llyn Arenig Fawr	n/a	n/a	Dŵr Cymru	
7.1	Chester STW effluent	-	27	Dŵr Cymru	

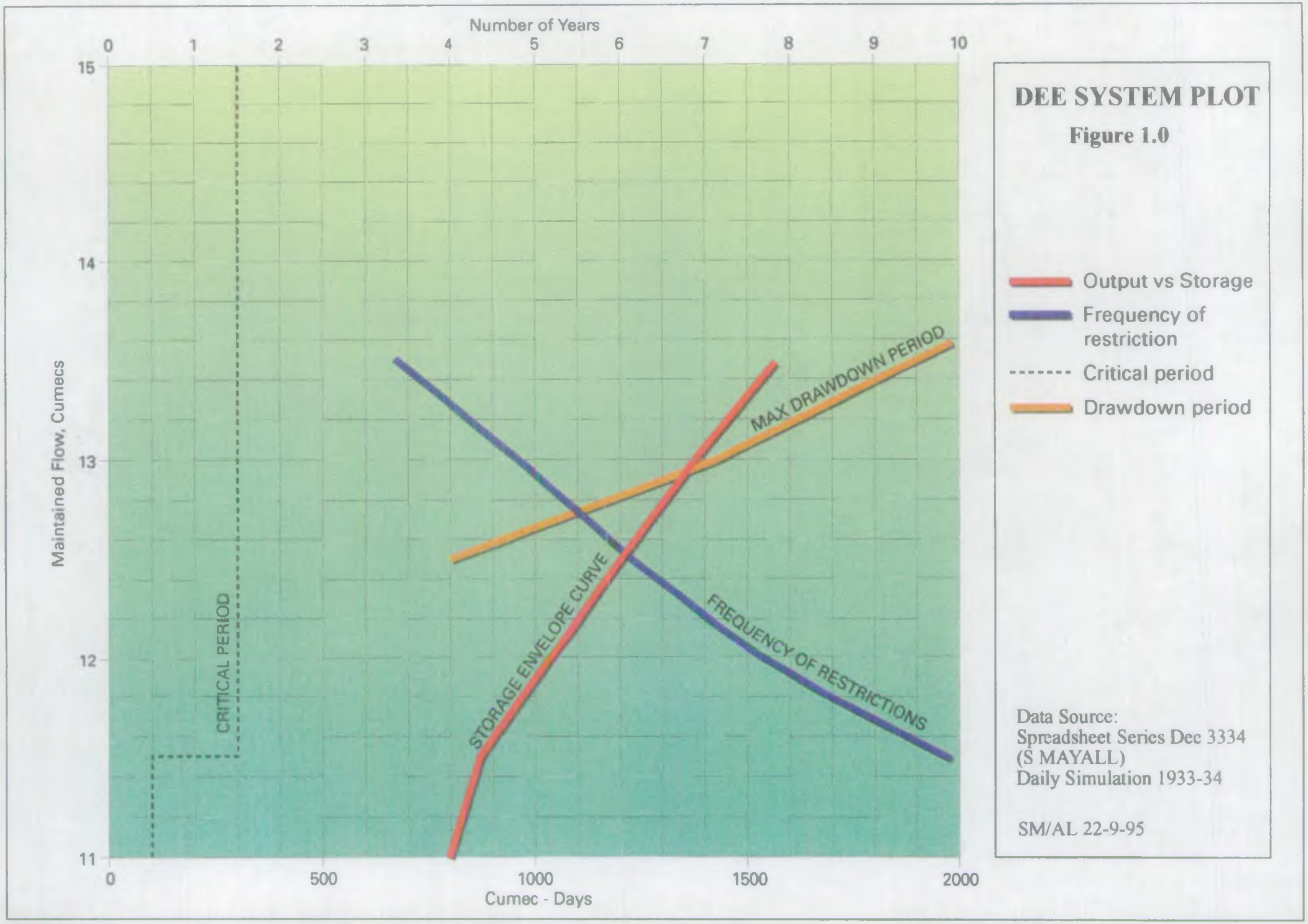
Comment: the Alyn scheme is the only one above which could be promoted without the direct or indirect involvement of Dŵr Cymru.

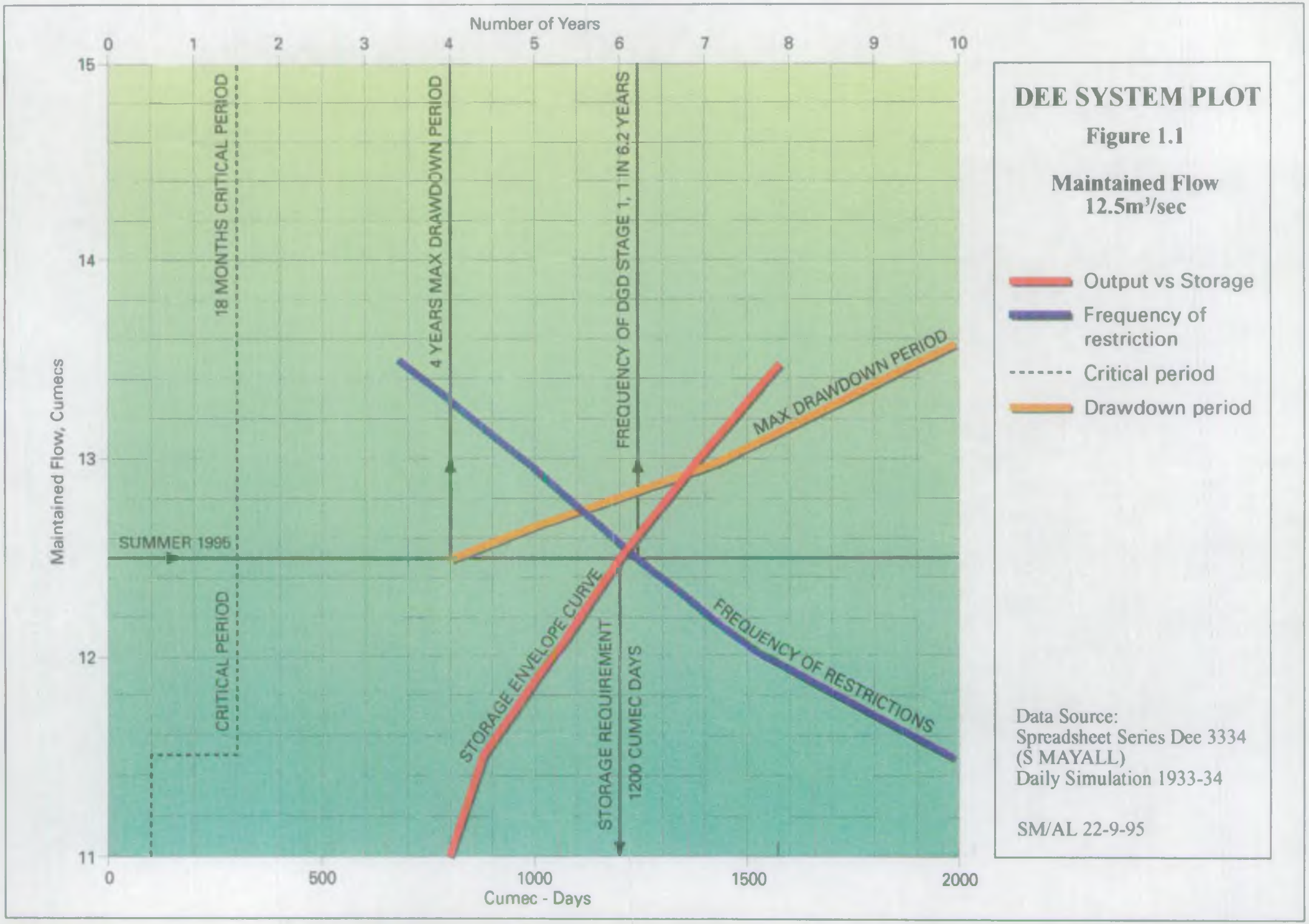
3.2.6 Other Options which NRA would have to promote

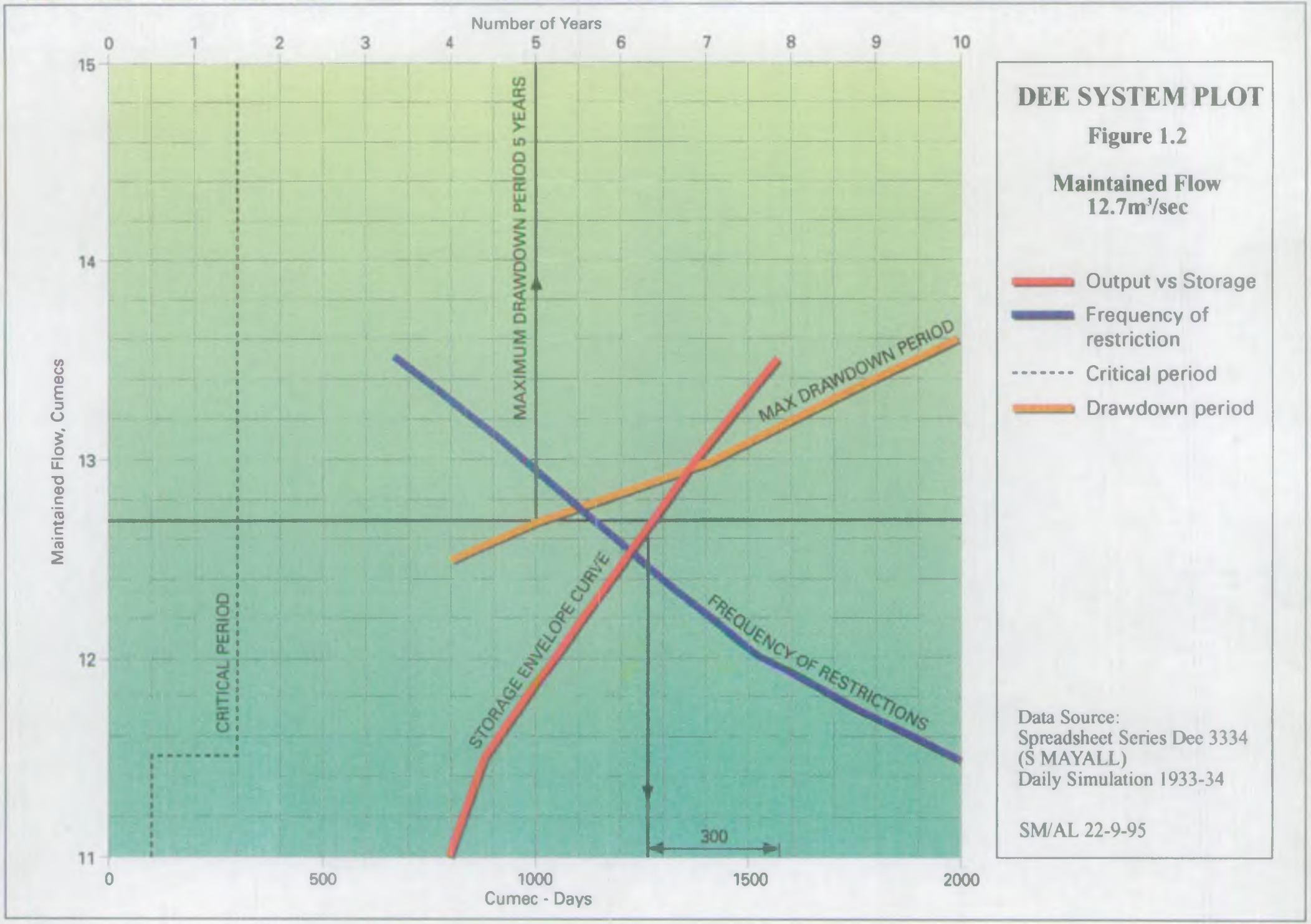
The following options, not previously mentioned, could only reasonably be promoted or initiated by NRA Welsh Region (and in some cases other NRA Regions):

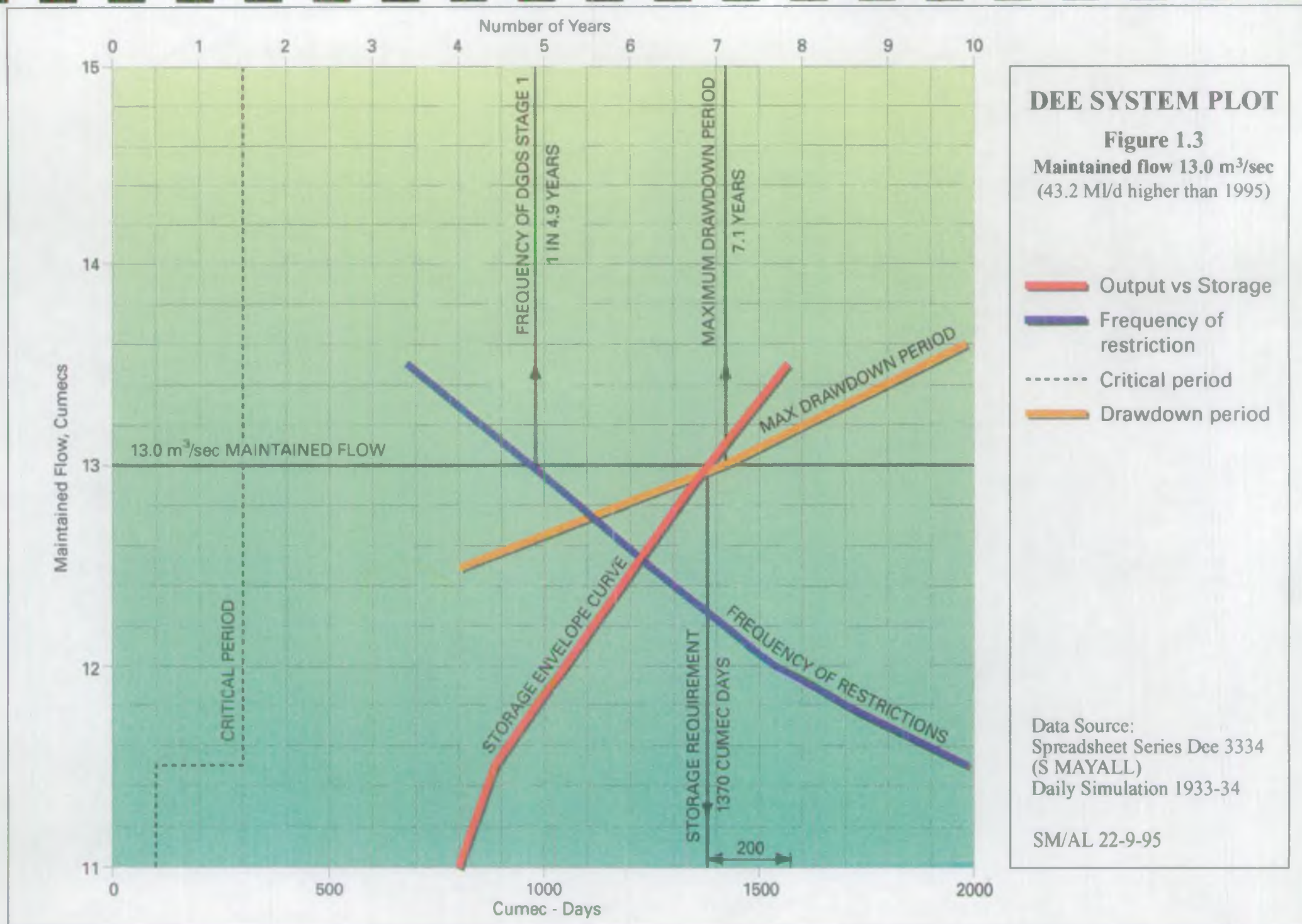
Table 13.

Option	Description	Other Associated Options
1A, 1B, 1C	Options involving Llangollen Canal/Vyrnwy/Severn regulation	
3.	Conjunctive Use, Tower Wood Boreholes	
4F.	Llyn Trawsfynydd (Dŵr Cymru/ Nuclear Electric)	5C4
5V1, 5V2, 5V3, 5V4.	Vyrnwy (Severn Trent NRA)	
8.1	Emergency measures in 2nd summer of 18-month drought	8.2


Number of Years
0
1
2
3
4
5
6
7
8
9
10
15
14
13
12
11
Maintained Flow, Cumecs
0
500
1000
1500
2000
Cumec - Days
CRITICAL PERIOD
STORAGE ENVELOPE CURVE
MAX DRAWDOWN PERIOD
FREQUENCY OF RESTRICTIONS
DEE SYSTEM PLOT
Figure 1.0
Output vs Storage
Frequency of restriction
Critical period
Drawdown period
Data Source:
Spreadsheet Series Dec 3334
(S MAYALL)
Daily Simulation 1933-34
SM/AL 22-9-95


Number of Years
0
1
2
3
4
5
6
7
8
9
10
15
14
13
12
11
Maintained Flow, Cumecs
18 MONTHS CRITICAL PERIOD
4 YEARS MAX DRAWDOWN PERIOD
FREQUENCY OF DGD STAGE 1, 1 IN 6.2 YEARS
MAX DRAWDOWN PERIOD
SUMMER 1995
CRITICAL PERIOD
STORAGE ENVELOPE CURVE
STORAGE REQUIREMENT
1200 CUMEC DAYS
FREQUENCY OF RESTRICTIONS
0
500
1000
1500
2000
Cumec - Days
DEE SYSTEM PLOT
Figure 1.1
Maintained Flow
12.5m³/sec
Output vs Storage
Frequency of restriction
Critical period
Drawdown period
Data Source:
Spreadsheet Series Dee 3334
(S MAYALL)
Daily Simulation 1933-34
SM/AL 22-9-95


Number of Years
0
1
2
3
4
5
6
7
8
9
10
15
14
13
12
11
Maintained Flow, Cumecs
MAXIMUM DRAWDOWN PERIOD 5 YEARS
MAX DRAWDOWN PERIOD
CRITICAL PERIOD
STORAGE ENVELOPE CURVE
FREQUENCY OF RESTRICTIONS
300
0
500
1000
1500
2000
Cumec - Days
DEE SYSTEM PLOT
Figure 1.2
Maintained Flow
12.7m³/sec
Output vs Storage
Frequency of restriction
Critical period
Drawdown period
Data Source:
Spreadsheet Series Dee 3334
(S MAYALL)
Daily Simulation 1933-34
SM/AL 22-9-95



DEE SYSTEM PLOT

Figure 1.3

Maintained flow 13.0 m^3/sec
(43.2 Ml/d higher than 1995)

- Output vs Storage
- Frequency of restriction
- Critical period
- Drawdown period

Data Source:
Spreadsheet Series Dee 3334
(S MAYALL)
Daily Simulation 1933-34

SM/AL 22-9-95

Recommendation 3:	
It is recommended that the NRA initiate discussions with interested parties in relation to the above options (excepting perhaps the Llyn Trawsfynydd transfer - Option 4F, initially). This would involve organisations both within Welsh Region and further afield. On a National scale, the following three issues warrant further investigation and consideration:	
1)	that conjunctive use of the Dee and Severn sources should be considered as part of National Strategy.
2)	that 17,300 or 25,900 Ml (200 or 300 cumec-days) of Brenig storage could form a better National Emergency storage (for Dee, Severn (via a canal link) or Thames) than the current national proposals to limit North West Water's use of Vyrnwy for direct supply.
3)	the merits of introducing pumped refill at Vyrnwy should be investigated.

4. FUNDING ISSUES

4.1 Introduction

4.1.1 The options and schemes identified in this report can be separated into two distinct groups when their funding is considered. Those listed as "small incremental Additional Yield" (Section 3.2.5 and Table 12) are, by their nature, schemes which benefit single operators. In these cases, where the need is proven, the benefitting individual abstractor will fund, promote and eventually develop the proposed scheme.

4.1.2 For major schemes, the benefits of new or additional works would be enjoyed (to a greater or lesser extent) by all the designated abstractors. The Dee Consultative Committee, the individual major abstractors, consortia of major abstractors, and the NRA could be expected to play a major role in promotion and funding of such schemes.

4.2 Funding of Schemes

4.2.1 The NRA has general duties in respect of water resources works, but has no specific duty in respect of the Dee, even under the Dee and Clwyd River Authority Act 1973. It does have powers to carry out works (as do the water companies), but in practice could not find the funds to do so. The water resources capital budget is insufficient to fund any of the proposed schemes; borrowing or "Grant In Aid" would have to be approved by the Department of the Environment. They are likely to say that the privatised water industry should fund developments which benefit it. NRA policy is that the Authority does not promote, fund and develop major water resource schemes . This policy was reinforced when the NRA withdrew from the Vale of York Scheme in the early 1990's.

4.2.2 The funding of any scheme should therefore come from the beneficiaries, either as a consortium with contributions perhaps pro rata to licensed entitlement, or individually.

4.3 Promotion of Schemes

4.3.1 The NRA must maintain its integrity as regulator, but equally its good name and impartiality are important assets in promoting water resources schemes. It would therefore seem appropriate that promotion should be undertaken by the Dee Consultative Committee, or a consortium of major abstractors. This would be particularly true if the scheme were to involve resource manipulation outside the Dee catchment. Abstraction and impoundment licences should be applied for by the organisation with eventual operational responsibility.

4.4 Operating Agreements

4.4.1 Section 20 of the Water Resources Act 1991 stipulates that "It shall be the duty of the Authority, so far as is reasonably practicable, to enter into and maintain such arrangements with water undertakers for securing the proper management or operation of -

(a) the waters which are available to be used by water undertakers for the purposes of, or in connection with, the carrying out of their functions; and

(b) any reservoirs, apparatus or other works which belong to, are operated by, or are otherwise under the control of water undertakers for the purposes of, or in connection with, the carrying out of their functions,

as the Authority from time to time considers appropriate for the purpose of carrying out its

function....such arrangements may -

(a) make provision ..... with respect to the construction or installation of any reservoirs, apparatus or other works which will be used by the undertaker in the carrying out of its functions;

(b) contain provision requiring payments to be made by the Authority to the undertaker; and.....".

4.4.2 The formation of the NRA in 1989 was accompanied by the signing of six such agreements between Dŵr Cymru and Welsh Region NRA. Those related to the areas covered in this report are for the Dee, Aled, and the groundwater river support scheme on the River Clwyd. At the same time three agreements were signed between Severn Trent Plc and Severn Trent NRA. Two of these cover the operation of Llyn Clywedog and Llyn Vyrnwy.

4.4.3 Within Welsh Region the Dee Operating Agreement is by far the largest, both in terms of financial value and in scheme size. Payment is equivalent to 2% of the asset value, and agreed operating expenses.

4.4.4 As the NRA believes that funding of any scheme should come from the beneficiaries, the Section 20 agreement provides a suitable mechanism. It enables the NRA to exercise overall control on the use of the regulated river, but the NRA would not own the asset. This not only provides benefit for all present and future abstractors, but also ensures that environmental benefits derived from regulation are maximised.

4.4.5 The Section 20 option is the mechanism of funding preferred by the NRA.

5. NEXT STEPS

5.1 This document has set out many options for discussion. It is clear that action is needed and that one option will not answer all the problems which the report has identified. However, there are potential solutions for:

* additional yield.
* enhanced level of service of existing supply.
* environmental benefits
* correction of past environmental damage.

5.2 The debate to explore the best way forward should now commence between those with a legitimate interest in the water resource use of the Dee and associated catchments. This document provides a catalyst for this debate.

5.3 The next step will consist of detailed investigations on costs and environmental impact of those schemes which are seen worthy of further work. This selection process will arise from the comments made on this document. It is, therefore, vital that all those parties invited to comment provide sufficient resources at this stage of the work.

5.4 To move the debate forward a seminar has been arranged for the 28th February 1996. This will enable a full discussion on the options identified. The 31st of March 1996 has been set as a deadline for formal comments. This will allow sufficient time to produce a final strategy by the summer of 1996. Formal comments should be sent to:

Mr Ian Barker
Water Resources Manager
National Rivers Authority
Rivers House
St. Mellons Business Park
St. Mellons -
Cardiff
CF3 0LT.

APPENDIX A: THE DEE REGULATION SCHEME

A1. The source of the Dee lies in the Snowdonia National Park. The course and topography of the river valley and its tributaries were strongly influenced and modified by glaciations which ended some 13,000 years ago. The catchment area of 1,816 km² 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 and 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 it is explained that they are living on the bed of a former lake with a narrow restricted outlet capable of passing only 12 millimetres (mm) of runoff per day when running full!.

A2. Annual average rainfall varies from 2,500 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 per year (36.8 cumecs). The table below 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.

Table 14.

Reservoir	Catchment Area (km^2)	Surface Area (ha)	Usable Capacity (Ml)	Average Runoff (cumecs)	Average Runoff (mm/yr)	Capacity /Runoff Days
Llyn Celyn	60	325	81,000	3.10	1590	302
Llyn Tegid	262	400	18,000	11.50	1380	18
Llyn Brenig	22	370	60,000	0.62	884	1120
Alwen Res.	26	150	15,000	0.73	899	238

A3. The four reservoirs control 17% of the catchment area, and 35% of the average runoff to Chester Weir.

1. Llyn Tegid is a natural lake up to 40 metres deep. It was first used for river regulation in the early 1800's, when Telford constructed a simple adjustable weir at the outlet to permit controlled releases for sustaining flows into the canal at Llangollen. In 1956, the present regulation facilities were constructed by lowering the lake outlet by approximately 2 metres, 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 2.5 cumecs). Llyn Tegid is in the Snowdonia National Park, with substantial water-based recreation (sailing, boating, fishing)

on and around the lake, which is now a 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 it releases flow. Much of the 81 million cubic metres storage was allocated to summer releases to support additional Dee abstractions of 3.4 cumecs, 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 cumecs) 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 years average runoff from its small catchment area, and in certain drought sequences (eg. 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 3.8 cumecs, utilizing a valley which was originally scheduled for a small direct supply reservoir with a yield of only 0.3 cumecs. 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 0.5 cumecs. 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 was used for generating power for operation of the associated local treatment works, but this is no longer the case. Proposals to generate hydropower from Llyn Brenig releases are under active consideration. Recreational activities on Alwen reservoir include fishing and water ski-ing.

A4. The Dee catchment area of 655 km^2 upstream of Corwen is predominantly rural, with a population of approximately 10,000 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 is 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 (eg. 1 in 5 year natural now occurs 1 in 10 years) and delayed the peaks sufficiently to allow farmers to clear their stock from the flood plains on receipt of flood warnings issued by the NRA. Where partial flood control is exercised, it is also essential to have an effective flood warning scheme to maximise the economic benefits of flood damage reduction.

A5. 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 from the addition of tributary flows, notably the Afon Ceiriog.

A6. 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 transverses 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 .

A7. 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. Within-bank spates also experience marked attenuation.

A8. 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 other associated industries, has been much less of a problem to the river environment since the Manley Hall regulated flow was raised from 2.9 cumecs to 8 cumecs after Llyn Celyn was built in the 1960s.

A9. 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 North West Water 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.

A10. However, tide heights regularly exceed Chester Weir crest level, and frequently cause strong (up to 60 cumecs) 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.

A11. The correct management of regulation releases during these tidal periods is critical, 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.

A12. 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.

A13. 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 metres, 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.

A14. 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.

APPENDIX B: DROUGHT GENERAL DIRECTIONS

With the passing of the "Liverpool Corporation Act, 1957", the operation of the River Dee sources was set through the Dee Consultative Committee. This group, consists of "the Authority" (now the NRA), designated abstractors (Chester Waterworks, Wrexham Water, North West Water and Dŵr Cymru) and British Waterways. It has the duty of:

* assisting the "Authority" in the formulation of "General Directions", and
* commenting to the Authority upon any such directions as proposed or issued by the Authority.

The detail of the "Dee General Directions" are contained in two documents :

* Dee General Directions - Sections 1 and 2 (December 1987)
* Dee General Directions - Section 3 (December 1987)

Additionally a "Dee Operating Manual" (March 1990) has been produced.

The following text outlines the general principles and policy of the Dee System, as detailed in the Dee General Directions. Reference should be made to the full documents, paarticularly with reference to its Appendicies which are not reproduced here.

SECTION 1

Principles and General Policy

1. Principles

1.1 Brief Statutory Background :-

Section 9 of the Dee and Clwyd River Authority Act 1973 specifies the present statutory framework for regulation of the River Dee using Llyn Tegid, Llyn Celyn and Llyn Brenig by the National Rivers Authority (NRA), known as the "Authority".

General Directions will be issued by the Authority consisting of Normal General Directions and Drought General Directions.

Provisions and safeguards govern the General Directions in relation to :-

a]. Section 27 [Supply of water from Tryweryn Reservoir] of the Liverpool Corporation Act 1957 refers to local bulk supply of water from Llyn Celyn.

b]. Prescribing a maintained flow except during a drought more severe than the design drought [estimated as once in 100 years severity] whilst having regard to :

i]. Mitigating flooding

ii]. Supplying British Waterways, Llangollen Canal in accordance with Section 4 of 0.328 m^3/sec.

iii]. Safeguarding the fisheries

iv]. Any other purposes which, in the opinion of the Authority, are appropriate and consistent with the purposes aforesaid.

c]. Section 16 Subsection [2] [Power to take waters of the Afon Tryweryn and other rivers and streams] of the Liverpool Corporation Act 1957 i.e. existing and proposed catchwaters to Llyn Celyn.

A Dee Consultative Committee is constituted with the duty to comment on and assist the Authority in formulating the General Directions.

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 Directions to cover unforeseen situations arising at short notice.

A disputes procedure is also allowed for.

1.2 Application of Statutory Background from 1974 to 1995

1.2.1 The designated abstractors in 1974 after the United Kingdom Water Industry Re-organisation were :-

Welsh Water Authority
North West Water Authority
Chester Waterworks Company
Wrexham and East Denbighshire Water Company

Dŵr Cymru, as successors to the Welsh Water Authority, themselves the successor to the Central Flintshire Water Board [designated abstractor] is entitled to one representative on the Dee Consultative Committee.

In its capacity as successor to the Dee and Clwyd River Authority, the Authority is entitled to have up to three representatives to comment and advise on the full range of river interests, not only river abstractions.

British Waterways is also entitled to one representative.

1.2.2 A major revision of the Dee General Directions was carried out in August 1979, following the first-filling of Llyn Brenig, and the consequent modification of North West Water Ltd., abstraction licences.

1.2.3 The 1979 issue of the General Directions incorporated certain points of principle, together with numerous detailed schedules and regulations relating to the operation of the Dee system.

1.2.4 In 1985 the General Directions were re-issued in their present format.

1.3 The Consultative Committee

1.3.1 The present members of the Committee are given in Appendix 1.2. The authorised daily abstraction quantities for the five designated abstractors of the River Dee are given in Appendix 1.3.

1.3.2 The Committee may decide when to meet or the Authority may convene a meeting. In addition, any body represented on the Committee may convene a meeting by written request to the Authority. The frequency of meetings varies widely in practice, meeting three or four times a year during critical dry periods and only meeting at other times to discuss changes to the Dee General Directions.

1.3.3 This revision, in 1985, of the Dee General Directions defines :-

a]. In Sections [1] and [2], those items which may be of some concern to the Dee Consultative Committee abstractors other than Authority, and on which they will wish to have detailed consultation.

b]. In Section [3] [Dee System Operating Manual], the specific operational instructions necessary for Authority personnel to run the multi-reservoir, multi-purpose system effectively.

Some items will be common to Section [2] and Section [3]. Some items in Section [3] only may be modified by the Authority Dee Consultative Committee representatives without full consultation with other representatives, provided that the other representatives are notified and their abstraction interests are not adversely affected by such actions.

SECTION 2

Detailed Points of Principle and Policy

2.1 Low Flow Regulation

2.1.1 Maintained flows will be based on the Eccleston Ferry flow measurement [using recorded river levels at Farndon] in order to incorporate all Dee tributary inflows upstream of Chester Weir and achieve a design minimum residual flow over Chester Weir of 4.2 m^3 /sec [363 Ml/d under Normal General Directions]. [A more detailed explanation of the Lower Dee flow measurement is given in Appendix 2.4].

2.1.2 As a general water conservation measure the River Dee will normally be regulated to provide an informal prescribed flow at Eccleston Ferry. This flow will be equal to the sum of the estimated actual [rather than licensed] daily abstraction requirements in the reach between Farndon and Chester Weir, plus the 4.2 m^3/sec design residual flow.

2.1.3 Drought General Directions may be introduced when total storage of Llyn Celyn and Llyn Brenig falls below the seasonal "System Conservation Rule Curve" [SCRC] [see Appendix 2.1].

2.1.4 Drought General Directions provide that when Celyn/Brenig storage is below the SCRC in May to November, the Authority may with the approval of all designated abstractors, suspend the "prescribed flow" method of regulation and opt for a "Stage 1" method under which the residual flow over Chester Weir is equal to the "natural" freshwater flow from the catchment area to Chester Weir when this is less than 4.2 m^3.sec. Additional releases necessary to prevent excessive build-up of saline water upstream of Chester Weir will be made during high spring tides. During this period the natural inflows to Llyn Tegid, Llyn Celyn and Llyn Brenig will be assumed to be 0.3 m^3/sec [26 Ml/d] in total. Appendix 2.2 details the formula to be used to calculate the net designated abstractions.

2.1.5 When "Stage 1" Drought General Directions are in operation, designated River Dee abstractors must reduce their Dee abstraction by all reasonable means including use of alternative sources and reduction of consumption including the application of general publicity and domestic hosepipe bans under Section 16 of the 1945 Water Act and to notify the Dee Consultative Committee of such actions. It is preferable that joint advertising of hosepipe bans is undertaken by Dŵr Cymru , Wrexham Water and Chester Waterworks Company.

2.1.6 When usable water conservation storage in the three regulating reservoirs falls to less than 70 days output under Stage 1 [or less than the quantity required to maintain abstractions until the end of November assuming no further effective rainfall] the Dee Consultative Committee shall meet to review the situation and determine what further measures [Stage 2] are appropriate for the circumstances existing at the time.

2.1.7 Whereas it is possible to define a specified volume of water conservation storage in Llyn Celyn and Llyn Brenig on 1st May each year [the nominal start of the low-flow regulation period], the effective water conservation storage in Llyn Tegid is not precisely definable as it depends upon use and re-use of a seasonal "bandwidth" of storage between an "Upper Conservation Limit" and a "Lower Amenity Limit".

2.1.8 Following the construction of Llyn Brenig, the full yield of the system exceeds both the current licensed and current actual abstractions. The 1985 total licensed abstractions of around 9.6 m^3/sec [830 Ml/d] together with a residual flow over Chester Weir of 4.2 m^3/sec show the Dee System has a critical period of two summers and one winter at this level of use. However 1985 actual abstractions totalled less than 6.9 m^3/sec [600 Ml/d] and at this level of use the Dee System has a critical period of one summer. The required Dee System Conservation storage on the 1st May for current net licensed abstractions is 1230 cumec-days [see Appendix 2.1]. This assumes that Llyn Tegid provides no yield to the system.

2.1.9 The Authority will use their best endeavours to ensure that the combined storage of Llyn Celyn and Llyn Brenig exceeds 1230 cumec-days on the 1st of May each year.

Any change in Section 3 which might reasonably be deemed to adversely affect the attainment of this objective must be referred to the Dee Consultative Committee.

2.1.10 The conjunctive use of Alwen Reservoir and Llyn Brenig compensation waters in accordance with Appendix 2.3 is approved and may be used at the discretion of the Authority for the effective use of resources in their area provided that it does not prejudice attainment of 2.1.9.

2.1.11 Except under Drought or Emergency General Directions the releases when regulating from Llyn Brenig shall not be such that the flow in the Afon Alwen at its confluence with the Dee at Corwen is greater than the River Dee flow.

2.2 Compensation Water Discharges

2.1.1 The following are the statutory compensation waters at ;

a]. Llyn Celyn

1st October - 31st March	0.368 m^3/sec [31.8 Ml/d]
1st April - 30th September	0.737 m^3/sec [63.7 Ml/d]

b]. Brenig/Alwen - minimum combined

1st October - 31st March	0.158 m^3/sec [13.6 Ml/d]
1st April - 30th September	0.289 m^3/sec [25.0 Ml/d]

subject to a minimum release of 0.053 m^3/sec [4.5 Ml/d] from either reservoir.

2.2.2 An unofficial compensation water discharge of not less than 2.5 m^3/sec [216 Ml/d] will normally be maintained below Bala Sluices.

2.3 Flood Mitigation

2.3.1 Llyn Brenig will not be explicitly operated for day to day flood mitigation, as its large surface area in relation to catchment area exhibits a major influence in the reduction of flood peaks in the Afon Brenig and the upper reaches of the Afon Alwen.

2.3.2 Llyn Celyn and Llyn Tegid will be used for short-term retention of flood run-off for flood mitigation purposes on the River Dee.

2.3.3 Maximum Retention Levels for Llyn Celyn, of between 1 and 3 metres below spillway level, are as recommended in the October 1980 Inspection Report under Section 2 of the Reservoirs [Safety Provisions] Act 1930. If Llyn Celyn levels exceed these values, maximum controlled discharges of 12.5 m^3/sec [1080 Ml/d] from Llyn Celyn are mandatory, irrespective of Llyn Tegid levels and discharges.

2.3.4 The general principles of flood mitigation will be :-

a]. Schedules and directions relating Llyn Tegid level to Llyn Tegid discharge, in order to safeguard the town of Bala from floods arising from possible inappropriate use of flood storage.

b]. Short-term retention of floodwater in Llyn Celyn and Llyn Tegid to reduce natural peak river flows in the Dee, particularly in the Bala to Bangor-on-Dee reach.

c]. Discharge of stored floodwater from Llyn Celyn/Llyn Tegid as rapidly as hydraulic constraints permit, once the flood peak has begun to recess down-river.

2.3.5 A flood warning scheme is in operation for the whole length of the River Dee. Specific warnings are issued by the Authority to the North Wales and Cheshire Police for dissemination to the public and other Emergency Services.

2.4 Other Matters

2.4.1 Hydro-electric power can be generated at Llyn Celyn and fed into the National Grid.

2.4.2 Recreation is a major activity in the area with sailing and other water sports on Llyn Tegid and Llyn Brenig and world class canoeing on the Afon Tryweryn with special releases from Llyn Celyn subject to the contingencies of the system.

2.4.3 Fishing takes place in Llyn Tegid, Llyn Celyn and Llyn Brenig and along the Dee from Bala to Chester. To assist migrating fish there are :-

a]. Fish passes at Chester Weir and Bala Sluices

b]. Special discharges [subject to Drought General Directions when in force] to encourage and protect fish movements upstream, and in summer, enhancement of the residual flow over Chester Weir particularly during periods of high temperatures and low natural flows and during the annual grilse run.

2.4.4 Subject to the requirements of 2.1.10 the Authority will utilise the special release water of the Dee Regulation System during short term emergencies associated with adverse water quality in accordance with DEEPOL procedures [DEEPOL - Joint Procedures agreed between river abstractors to co-ordinate action and disseminate information during periods of adverse water quality].

APPENDIX C : TABLE OF MAJOR SOURCES IN THE DEE & ASSOCIATED CATCHMENTS.

Site	Grid Ref.	Catchment	Resource Type	Capacity Ml (cumec-days)	Licence (Ml/d)	Owner
Vymwy	SH 990 215	Severn	Direct Supply Reservoir	59552.6		Severn Trent/ North West
Brenig	SH 980 560	Dee	River Regulation	600007.2	5500	Dŵr Cymru
Alwen Reservoir	SH 955 528	Dee	Direct Supply	14529.0	45.46	Dŵr Cymru
Llyn Alwen	SH 898 565	Dee	Natural Lake			
Llyn Aled	SH 920 570	Clwyd	Reservoir	1704.8		Dŵr Cymru
Aled Isaf	SH 910 590	Clwyd	River Regulation	1227.4		Dŵr Cymru
Tower Wood	SJ 503 541	Dee	Boreholes		6.8	Severn Trent
Llyn Celyn	SH 860 405	Dee	River Regulation	74008.9	1136.5	Dŵr Cymru
Llyn Conwy	SH 780 460	Conwy	Reservoir	363.7	4.83	Dŵr Cymru
Llyn Trawsfynydd	SH 690 370	Dwyryd	Power Generation	32549.4	639.36	Nuclear Electric
Llyn Bran	SH 963 591	Dee	Reservoir		1.45	Dŵr Cymru
Llyn Arenig Fawr	SH 847 380	Dee	Reservoir	1622.9	2.27	Dŵr Cymru
Llyn Arenig Fach	SH 828 417	Dee	Reservoir			Dŵr Cymru
Llyn Tryweryn	SH 789 385	Dee	Natural Lake			
Cilcain	SJ 164 646	Dee	Reservoir	170.5	4.55	Dŵr Cymru
Brithdir	SJ 178 627	Dee	Reservoir	36.4	4.55	Dŵr Cymru
Pen-y-felin (Cynwyd)	SJ 067 405	Dee	Reservoir	40.9	1.8	Dŵr Cymru
Wrexham Reservoirs		Dee	Reservoirs	1636.7	21.46	Wrexham Water

APPENDIX D: PEOPLE CONSULTED DURING THE STUDY

This project was carried out for the National Rivers Authority (Welsh Region) by Allan Lambert of A.O.Lambert Consultancy Ltd. The project manager, Bob Vaughan, and Allan Lambert would like to thank the following colleagues for their assistance in the production of this report :

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Severn Trent Water	Richard Douglas	3
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Dŵr Cymru - Brecon	Logan Jack	1

APPENDIX E: RELIABILITY OF REFILL

The problem can be simply expressed. With abstractions at full licensed quantities, at the end of a single summer drought, the Dee regulating reservoirs, Alwen Reservoir and Vyrnwy would all be around 40% to 50% full. Single summer droughts have occurred in 1933, 1937, 1947, 1949, 1959, 1964, 1975, 1984, 1989 and 1995. In most subsequent winters, all the reservoirs (except perhaps Llyn Brenig) would fully refill from natural runoff. However, if a dry winter (such as 1933/34, or 1975/76) occurs, all the reservoirs start the second summer with only around 40% to 60% of full storage. Severe water conservation measures would undoubtedly have to be carried out throughout North Wales and North-West England, from April onwards, in case the coming summer turned out to be drier than average.

The frequency of restrictions is more closely related to emergency measures for dealing with what **might** happen, than to statistical analyses based on what happened in the past. This has the benefit of hindsight in knowing when the drought ended, a luxury not available to operators in real drought events.

APPENDIX F: ACTS AND PARLIAMENTARY ORDERS RELATING TO THE DEE.

Water Resources Act 1991
Dee and Clwyd River Board Act 1951
Liverpool Corporation Act 1957
The Dee and Clwyd River Authority (Brenig Reservoir) Order 1972.