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Assessment of Kielder Yield

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INTRODUCTION

This study aims to provide a brief review of the yield available from Kielder reservoir, taking into account present restrictions on drawdown. The effect of additional abstractions on the water levels are examined for two different strategies, one supplying a fixed amount of water each week from the reservoir, and the other linking into the Esk river, and supplying quantities, as called upon, for flow augmentation.

The report is divided into several sections. The first describes the data available and the analyses required to provide continuous series of flows. The second describes the formulation and underlying assumptions of the model. The third section presents the modelling results and examines the implications of these, and finally there follows the summary and conclusions. The appendix accompanying this report provides a printout of the database produced for this project which is in the form of a set of HYDATA data files.

2. AVAILABLE DATA AND DATA ANALYSIS

Figure 1 is a map of the area showing the gauging stations used in the analysis. A complete listing of the daily flow data used for this study is provided in the data appendix, however a summary of the information provided by the NRA is shown in Table 1.

Table 1 Available data

Station number	Period available	Missing periods
23003 (Reaverhill)	-1989	Oct-Dec 1988
23004 (Haydon Bridge)	-1989	Sept 1989 (17th-26th)
23005 (Tarset)	-1983	
23008 (Rede Bridge)	-1989	
23022 (Uglydub)	1982-1989	Jan-Apr, Aug-Oct 1982, + Oct 83, + part Nov 1988

The model of the Tyne relies on continuous records at Reaverhill and Haydon Bridge; and continuous Uglydub flows are required to calculate inflows to Kielder reservoir for recent years. The reservoir storage has been available for river flow augmentation since 1982, and it is particularly important to include the most recent information due to the unusual nature of the recent low inflows as discussed later. It is also important to have as long a period as possible to indicate the behaviour of the reservoir during other than drought situations. For this we have needed to infill the series to provide continuous data from 1982 to 1989 as follows:

Location map showing gauging stations

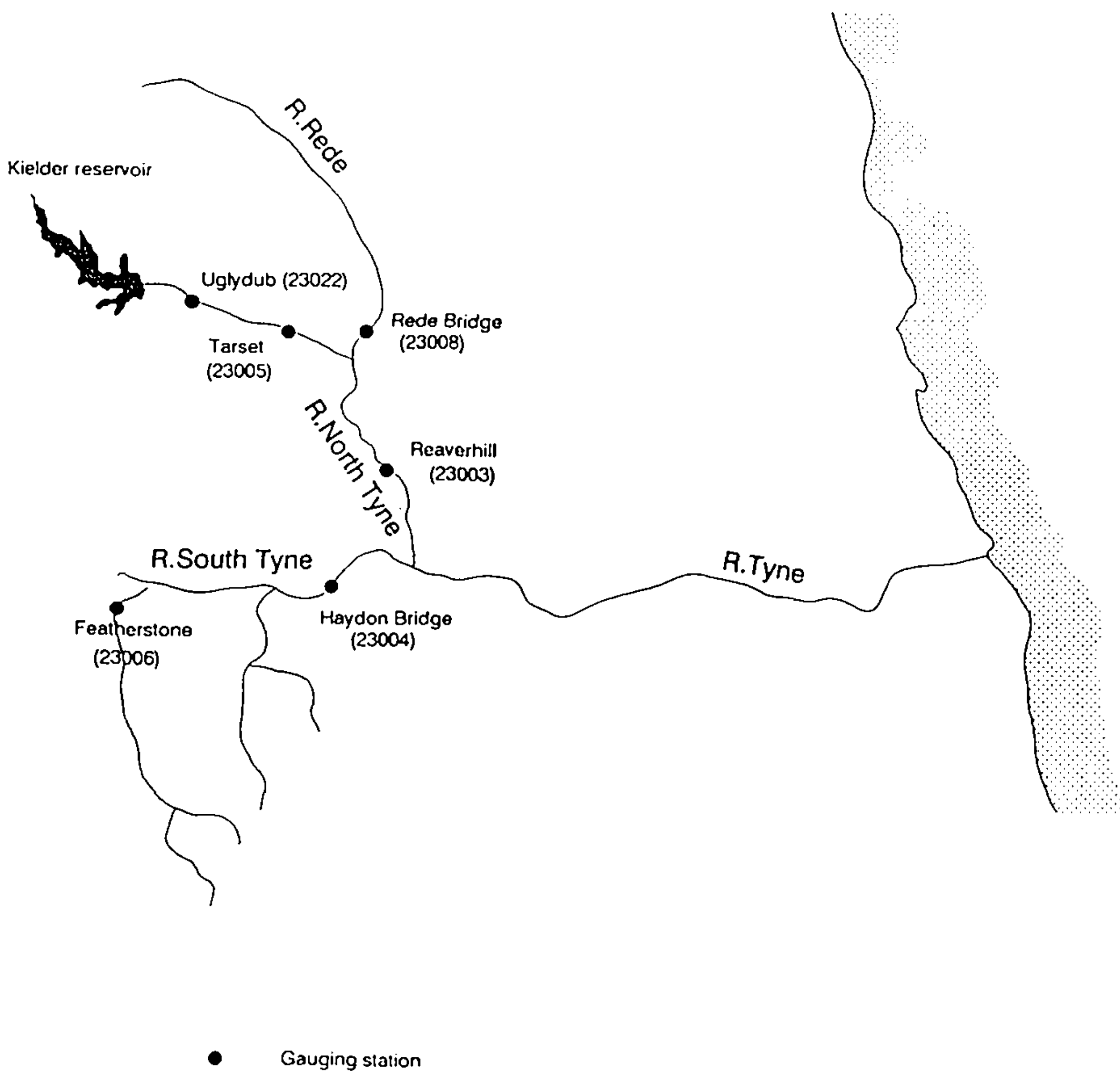

Figure 1

2.1 23003- Reaverhill

The Reaverhill daily flows are used to provide a series of intermediate catchment flows, downstream of Kielder reservoir, by subtracting the Uglydub record. The resulting series contained many negative points, so the flows for the two stations were plotted as comparison time series (using HYDATA) to investigate these values. The plots are reproduced in the Appendix Figures A1 to A6. There were two main reasons for negatives; firstly there are, inevitably, small inaccuracies in flow estimation at each site. If the flows are very similar there will consequently be small positive and negative values recorded for the difference rather than exactly zero. Secondly there is a small lag between releases at Kielder and the flows reaching Tarset. This lag occasionally shows up in the record with a negative value during the rising limb of an event, followed by a larger than expected positive value when the releases are reduced. Both of these cases cause negative differences in the flows at Uglydub and Reaverhill but for the purposes of yield and storage calculations they are insignificant.

The storage yield analysis was conducted on a weekly basis which eliminated most of these negative values. It is interesting to note here that there were sustained periods of small negative differences recorded in the summer of 1989. It could be that this was merely due to Uglydub and Reaverhill flows being very similar, but it could also reflect the lack of water in a drought period leading to slight reduction in flows as they travel downstream.

Having provided a series of intermediate catchment flows from these two stations it was necessary to infill the gaps caused by the lack of data at either or both stations. A regression was therefore carried out between this difference of flows (station 3000 in the Appendix) and the nearby Rede Bridge station (23008). The regression equation, using data from 1982 to 1988 inclusive, was:

DIFF = 1.24 + 1.98 Rede Bridge Correlation coeff 81.7%

This equation was based on series 3000 values including negatives. A regression was also carried out ignoring negative values. The equation was very little different from that above. As it has been shown that the negative values are mainly within the bounds of acceptable hydrometric accuracy the first equation was used to infill the record. The resulting infilled series is Station 3000 in the appendix.

2.2 23004- Haydon Bridge

The Haydon Bridge record was used to represent inflows from the other main catchment contributing to the North Tyne flows. The record is complete apart from a short gap in September 1989. The 1989 information is important for this project and so the upstream station at Featherstone (23006) was regressed against Haydon Bridge (only using September 1989 information) producing the equation-

Haydon = 0.417 + 0.942 Featherstone Correlation coeff 97.2%

Only a short record was used for the regression, but the missing period is short and the regression had a high correlation coefficient so we believe this is adequate.

2.3 23022-Uglydub (Kielder releases)

Uglydub records are required to calculate inflows to Kielder reservoir after 1986 (pre 1986 are available from the NRA). A regression was carried out between Uglydub and the downstream Tarset station (23005). Unfortunately Tarset was discontinued in 1987 but it did exist during the missing periods of 1982 and 1983. The regression equation produced using information from 1982 to 1987 was

$$\text{Uglydub} = 0.0502 + 0.844 \text{ Tarset}$$

The correlation coefficient was 96.4% which is quite acceptable for the small periods which require infilling.

Tarset could not be used to infill the missing period in 1988 which was important as a run up to 1989. The missing period was only 9 days during which nearby stations did not exhibit a major response to rainfall, and so the data were infilled using logarithmic interpolation. Station 23022 in the Appendix includes the infilled information.

2.4 Kielder inflows

Estimates of the daily net inflow to the reservoir, prior to May 1986, were made available by the Northumbrian NRA.. Subsequent inflows were estimated using the following water balance equation:

$$I = S + O$$

where I is the inflow over 24hrs
S is the 24 hr change in storage

and O is the outflow over 24 hrs

Any evaporation is incorporated in the change in storage terms (S). Negative values occur when reservoir releases exceed inflow.

Outflows were recorded at the Uglydub gauging station just downstream of the dam. The daily reservoir volume was estimated from a record of water levels, measured at 9 am each day. The equation below was determined by linear regression of level and storage data, also provided by Northumbrian NRA:

$$V = 0.017(E \quad 139.561)^{2.45}$$

where V is the volume of water stored
E is the elevation of the water surface.

Values obtained using this equation compared well with those determined prior to May 1986. The difference over 24 hours represented the daily change in reservoir storage.

2.5 Abstraction information

Records of the major abstractions at Barrasford, Riding Mill and Ovingham available in the form of monthly total abstractions and number of days, for the period May 1982 to the end of December 1989. These were converted to weekly volumes for the Tyne catchment model.

THE MODEL

A full model of the Tyne, Tees and Wear rivers would be required, together with long sequences of inflows, if a rigorous statistical analysis were to be carried out showing the effect of additional abstractions from Kielder reservoir. In the time available for this study it is not possible to carry out this level of modelling, but a simplified model of the Tyne for the period 1982 to 1989 has been constructed. Outside this period there are no abstraction records for the Tees and Wear and the full scale model would be required for estimation of these.

Figure 2 shows a diagrammatic representation of the mathematical model developed to estimate Kielder water levels. The model was run on a weekly time scale, in units of million cubic metres, to minimise limitations in the data. It was split into two parts, one determining the demand on Kielder from the downstream catchments, and the other modelling the response of Kielder storage to inflows and abstractions.

3.1 The Tyne river model

The catchment model accumulated abstractions and inputs in the Tyne catchment starting at the downstream end at the Ovingham offtake. Here there is effectively a mean minimum flow in the river of 50Mgd (227.3 Mℓ/d). The weekly abstractions for Ovingham and Riding Mill were added to this to provide a series of lower Tyne demands. These were subtracted from the Haydon bridge weekly volumes to provide a series of unsatisfied system demands. The total demands on Kielder were then calculated using the lower Tyne unsatisfied demands, the abstractions at Barrasford, and the inflows of the intermediate catchment. The intermediate catchment values, calculated by taking Uglydub flows from Reaverhill records, inevitably provide some negative flows but the use of a weekly model helped to eliminate these. The resulting series of values is a series of weekly downstream demands for the years 1982 to 1989 which have to be provided from Kielder storage.

3.2 Kielder reservoir model

The reservoir model carried out a weekly water balance of the reservoir

Model of Tyne Water Resources

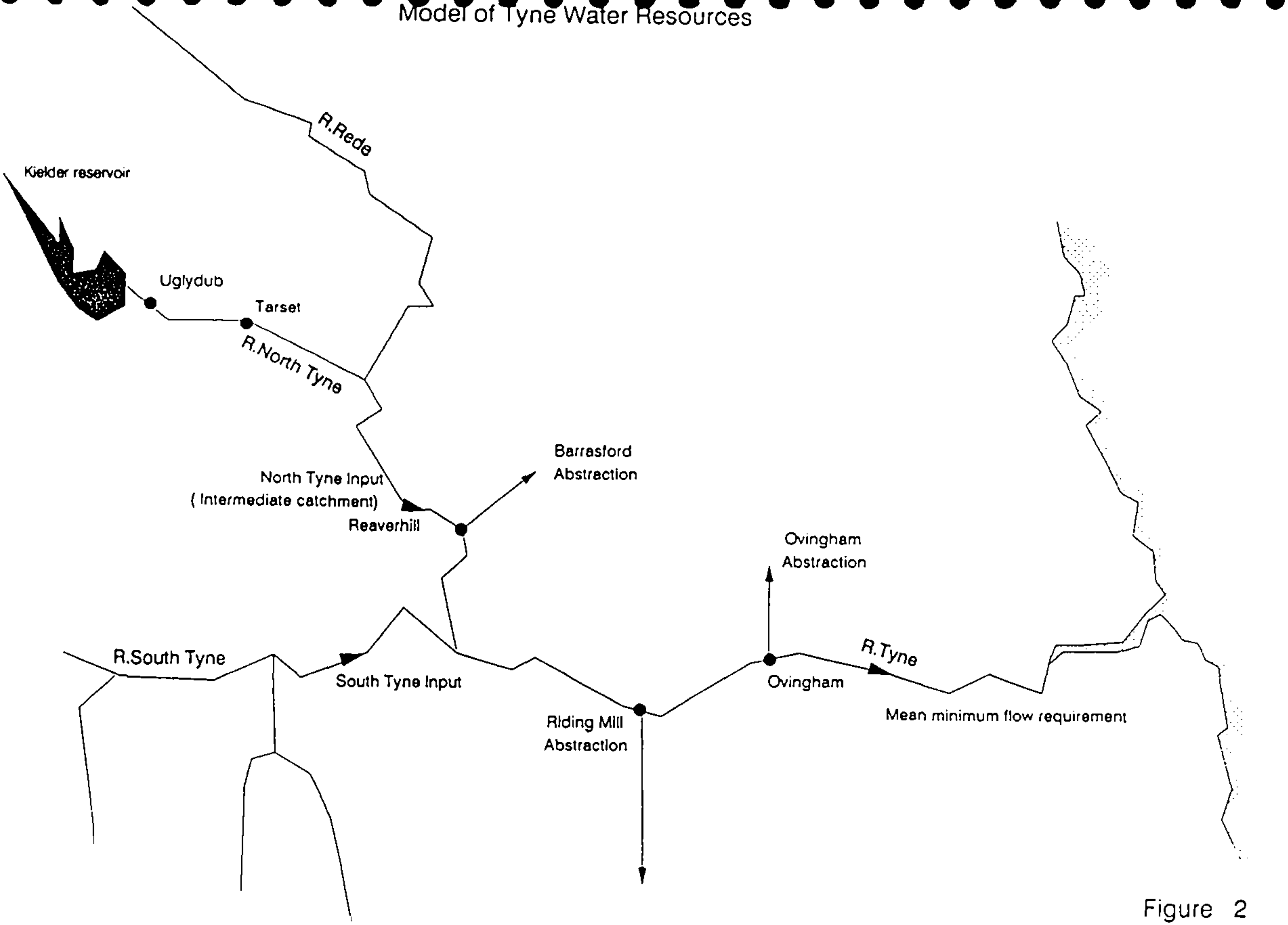

Figure 2

storage from May 1982 to December 1989

S2 = S1 + INFLOWS   DEMANDS

S2 and S1 are the end of week storages for the present time step and the previous time step respectively. The inflows are from NRA records and as calculated in the data section (from reservoir water levels), and the downstream demands the greater of results from the lower Tyne model and the compensation flow at Uglydub.

A starting water level of 183.4m is used based on a graph of average Kielder level control and the first abstraction information for May 1982. From this basic setup it is possible to carry out simulations of the reservoir. Additional abstractions can be imposed on the reservoir, and the results recorded as a time series of water levels.

4. MODELLING RESULTS AND DISCUSSION

4.1 The Model period 1982 to 1989

Since the completion of the dam and the filling of the reservoir in 1982 the UK has experienced two periods of drought; in 1984 and 1989. The drought of 1984 resulted in annual minimum discharges on the River Esk, with return periods of the order of 25-50 years (Institute of Hydrology, 1990). It is likely that the return period of flows on the North Tyne would have been of a similar order, had the Kielder Reservoir not been present.

The 1989 drought was particularly severe in north east England and Scotland. The Northumbrian region experienced an extended drought with an accumulated rainfall total from November 1988 to December 1989 of just 732 mm (70% of the long term average). Such an unprecedented period of low rainfall is estimated to have a return period of 100-200 years (Institute of Hydrology, 1989). This low rainfall resulted in December one day minimums on the River Derwent (Yorkshire) and the River Tweed (Northumbria) with return periods of 50-100 years. Once again it is likely that the return period of low flows on the Tyne would have been of a similar order, had the Kielder Reservoir not been present. For this reason we felt it was important to include 1989 information.

4.2 The present yield of Kielder reservoir

The first simulation of the reservoir was carried out with only the calculated downstream demands and existing compensation flow requirements. The water levels recorded show that the reservoir spills for much of the time. The effect of additional abstractions on the reservoir water levels was investigated and results plotted in Figure 3 showing that a total weekly abstraction of 500 Mℓ/day each week could have been supported through the period, with a maximum drawdown of approximately 10 m. Drawdown below 10 m is unacceptable as provision has to be made for grassing exposed banks. Although it is not possible to provide estimates of system yield from such a

Water Resources of Kielder reservoir

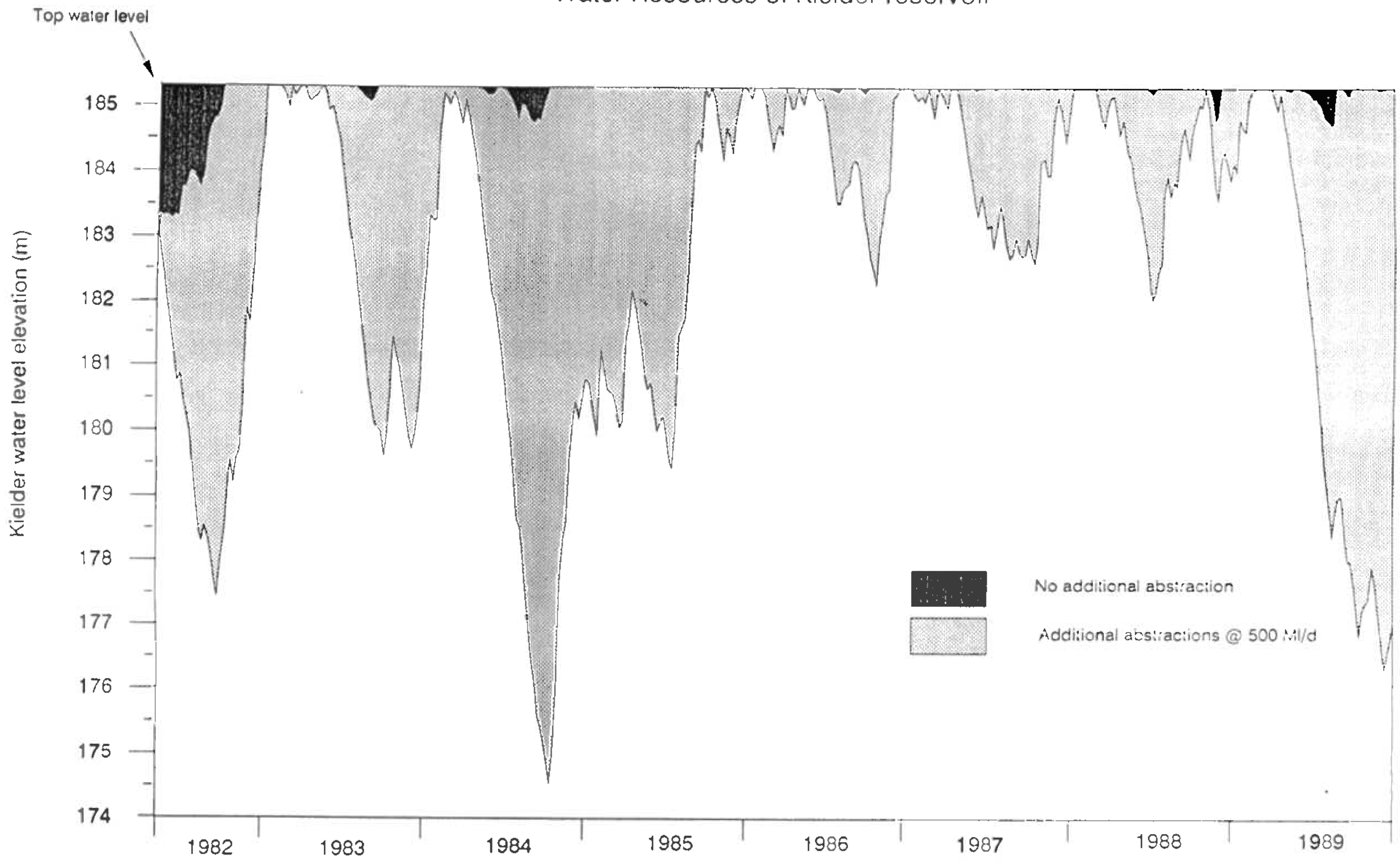

Figure 3

short data-set the simulation above describes the resources available through a particular historic period which has been shown to contain two dry periods. This gives an overall figure for additional resources available in Kielder, within present drawdown restrictions, and over the limited historic period.

4.3 Response to additional abstractions - Direct supply

Having established the approximate extent of the resources available to supply, simulations were carried out to show the effect of particular bulk abstractions from the reservoir to supply 50, 100, and 150 Mℓ/d. The simulations were carried out with augmentation of the Tyne system, plus additional bulk abstractions of the above figures with 15% transmission loss allowance. The results are shown in Figure 4. The shaded areas represent the additional drop in water level as a result of the direct abstractions, compared with the original water level series satisfying only Tyne demands. If 1982 is considered as a 'start up' year for the model it can be seen that the reservoir water levels do not drop below 3 m drawdown even during the drought periods of record.

4.4 Response to additional abstraction - River regulation

A more realistic representation of the abstractions required from Kielder for proposed augmentation of the Esk is realised by linking the Kielder model to the historic flows in the Esk. Results of regulation releases required for Esk augmentation are presented in the recent report "River Esk Hydrology" (1990). From this report, the abstraction plus the minimum acceptable flow (of 15% of the mean flow i.e. 321 Mℓ/d) is calculated as 371, 421 and 471 Mℓ/d for abstractions of 50, 100 and 150 Mℓ/d. These requirements were deducted from the historic Esk flow series to produce three composite series with both negative and positive flows. The negative flows indicate periods where the Esk would not be capable of supporting the demand required; and the size of the negative flow indicates the quantities needed for river augmentation. These quantities were increased by 15%, to allow for transmission losses, and were used as additional demands on Kielder. The results of the water levels resulting from these simulations are shown in Figure 5.

4.5 Discussion

1982 can be considered a 'start-up' year for the simulations as the results of water level are dependent on the starting water level chosen. Under the abstraction policies tested the reservoir fills at the end of 1982, and thereafter the water levels are independent of starting contents.

Both sets of results, from 4.3 and 4.4, show the effect of the dry periods 1983-84 and 1989. Interestingly the extreme rainfall for 1989 is not reflected directly in extreme water levels. If anything, the effect on storage is less severe than that for 1984.

Results for 4.4 indicate that the river Esk did not have such extreme low flow conditions in 1989 as the Tyne. Demands on Kielder water are much

Comparison of effects of direct abstractions from Kielder

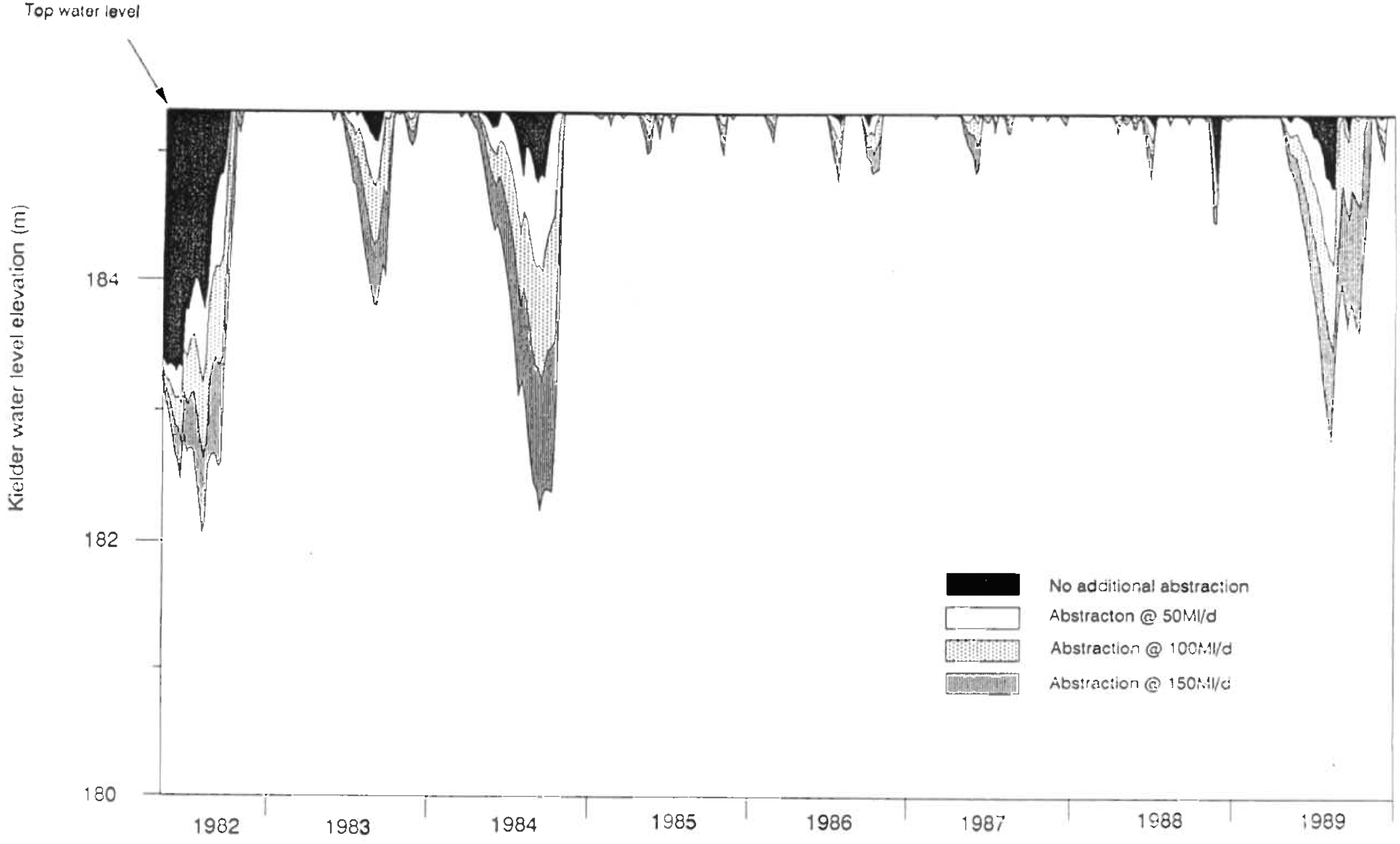

Figure 4

Comparison of effects of abstractions from Kielder for Netherby Flow Augmentation

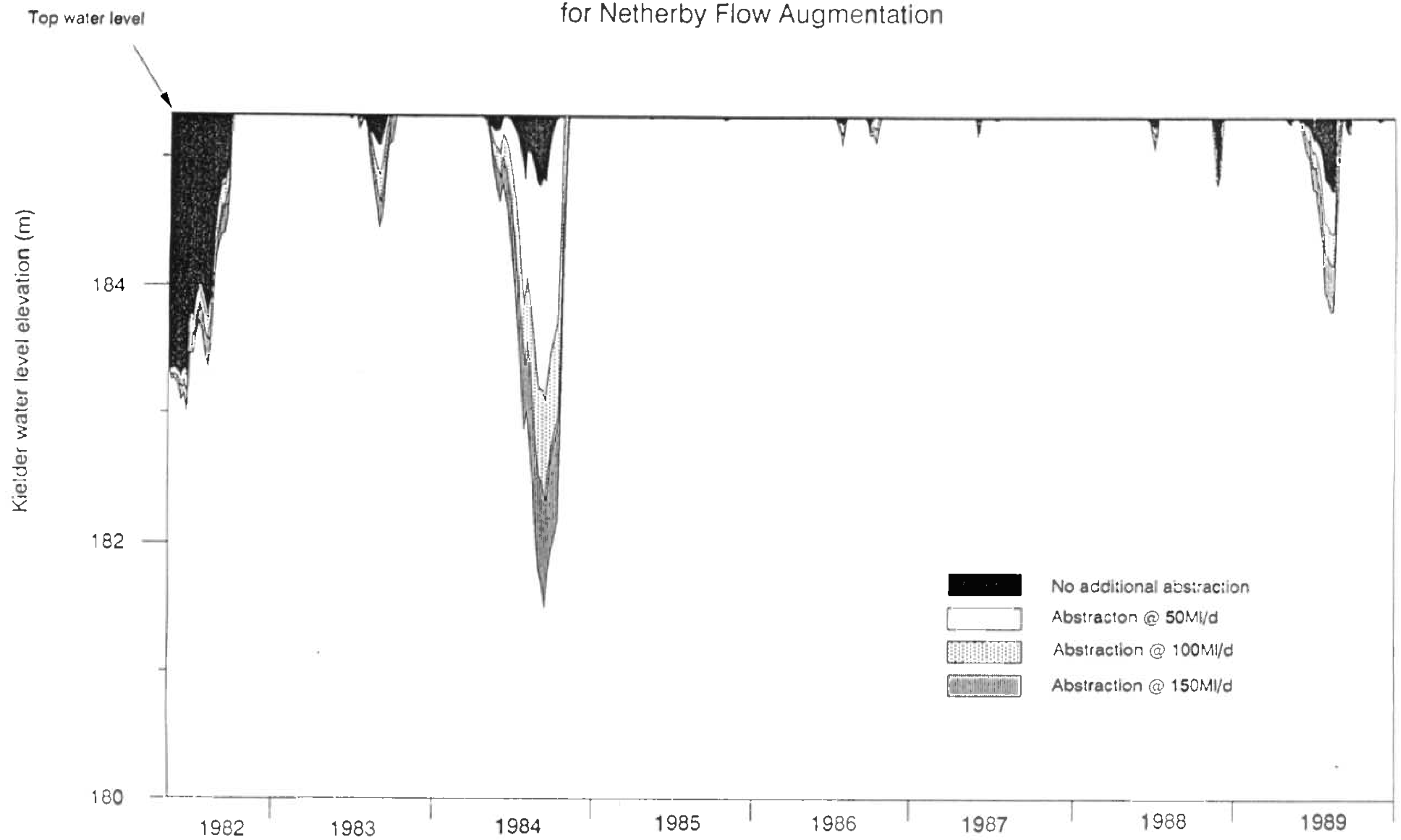

Figure 5

lower than for 1984. This ties in with the fact that 1989 low flows were particularly severe in the north east region.

An attempt at assessing the return period of these events is impossible with such a short record, and thus the return period of rainfall must be used as an indication of the frequency of the events. Therefore the resulting water levels for the 1984 and 1989 low flow periods indicate the effect of the abstractions during a greater than 25 year return period low flow sequence.

Throughout these simulations the hydropower potential of Kielder has been ignored, but there are significant periods of spill during which additional hydropower generation would have been carried out. An additional simulation could easily be tested at this stage, incorporating a simple operating rule, to show the hydropower resources available under the likely future operating scheme.

SUMMARY

A simple model has been constructed of Kielder reservoir and the river Tyne major abstractions. Simulations have been carried out for the period May 1982 to December 1989 to show the effect of additional abstractions on the reservoir water level. The results of the simulations are presented in Figures 3, 4 and 5 showing that the bulk transfers, as a direct supply and transfers for river Esk regulation, did not cause the reservoir water level to be drawn below 182 m. It is estimated that these low flow periods reflect conditions expected with a greater thna 25 year return period.

REFERENCES

Institute of Hydrology, (1987), HYDATA.

Institute of Hydrology, (1989), Hydrological Summary December 1989. Internal Report.

Institute of Hydrology (1990), River Esk Hydrology. Report prepared for British Nuclear Fuels plc.