NATIONAL RIVERS AUTHORITY
ANGLIAN REGION

EXTENDING RUTLAND YIELD ANALYSIS TO 1933

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Supporting Documentation for the
Regional Water Resources Strategy

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This is the third report in a series of supporting documents for the Anglian Region Water Resources Strategy. Documents in the series are:

1 Preliminary modelling of water storage and transfers in the Anglian Region

Steve Cook, Glenn Watts & Nigel Fawthrop May 1993

This report describes the models used in the yield analysis of the Trent-Witham-Ancholme system, the Ely Ouse - Essex system, and Rutland Water and Grafham Water. Results are presented for a variety of options for operation, including the possibility of connecting all of the systems to allow augmentation from the Trent.

2 Reconstruction of historic Witham flows

Glenn Watts July 1993

This report describes the methods used to extend flow records for the River Witham back to 1933, together with an analysis of the errors associated with the extended flow records. The long flow records can be used in the analysis of the effect of transfers from the River Trent to the Trent-Witham-Ancholme system and from there to the Ely Ouse - Essex system.

3 Extending Rutland yield analysis to 1933

Glenn Watts August 1993

(This report)

Summary

The yield of Rutland Water is calculated using a model which simulates the behaviour of the reservoir using historic flow records. For the most important component of the Rutland system, flow in the River Nene, gauging started in 1940. Yield analysis previously started at this date.

Analysis of the yield of other reservoir systems in the Anglian Region has shown that the drought of 1934 to 1935 is the most severe on record. To allow comparison of the yield of Rutland with the yields of other systems, it is necessary to analyse the behaviour of the reservoir from 1933 onwards. This report describes the methods used to extend the flow records required for Rutland yield analysis.

The effect of the extension of the records is considerable; for 1992 conditions the yield calculated using the records from 1933 to 1992 is 45 tcmd (almost 20%) lower than that calculated using the 1942 to 1992 period. Limited testing of the extended records suggest that they should provide a reasonable estimate of reservoir yield. However, there is room for improvement in the simulation of Nene and Welland flows, and consideration should be given to this.

The results emphasise the importance of the 1930s drought in assessing the yield of Rutland Water. Any analysis which does not consider this period will overestimate Rutland yield.

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1 Introduction

The yield of Rutland Water has been evaluated using a model which simulates the behaviour of the reservoir. To allow behaviour to be simulated over an extended period, historic flows are used in the model. These are naturalised to remove the influence of abstractions and discharges from the record; in the model they are denaturalised for future conditions. The yield derived is generally thought to be most representative if a long flow sequence can be used, as this long sequence should contain conditions representative of those likely to occur in the future.

The yield of Rutland depends most on flows at Wansford, on the River Nene, which is the major Rutland intake. Flows are gauged at Orton, downstream of Wansford; these flows are used for Rutland yield analysis. Gauging started in October 1940, so yield analysis has used 50 years of record.

For the NRA Anglian Region Water Resources Strategy, the possibility of augmenting various important surface water sources is being considered. Options include augmenting Rutland from the Trent, augmenting the Ely Ouse - Essex system from the Trent, augmenting Grafham from the Trent, or constructing a new reservoir in the Ely Ouse - Essex system. To allow comparison of the benefits of each of these options, they must be evaluated over the same simulation period. For analysis of the yield of the Ely Ouse - Essex system, the most critical period is 1934 to 1935, when there was a severe and prolonged drought. Therefore to allow comparison between Rutland yield and the yield of the other systems the Rutland analysis needs to extend to 1933. This document describes the extension of the records required for Rutland analysis to start in 1933.

The time available for this work was around one week. This lead to simplifications which may limit the confidence attached to the results. There is a need for revision of some of the methods used. However, the preliminary data described in this report is useful in the extension of Rutland yield analysis.

2 Rutland yield simulation data requirements

The Rutland reservoir system is complex and the model has considerable data requirements. The two intakes for Rutland are on the Nene at Wansford and the Welland at Tinwell. The model requires naturalised flows for both of these locations.

There are two other important impounding reservoirs upstream of the intakes. Pitsford impounds a tributary of the Nene and is also fed by pumping water from the Nene at Duston. Eye Brook Reservoir impounds the Eye Brook, a tributary of the Welland. Both of these reservoirs directly influence gauged flows at the Rutland intakes, and therefore they need to be accounted for in the naturalisation procedure. As it is envisaged that these reservoirs will still exist in future, the yield simulation needs to simulate their operation. Natural inflows to the reservoirs are needed by the simulation model.

Rutland Water has natural inflows. These come from two small streams and rainfall falling directly on the surface of the reservoir. As Rutland has a large surface area, the volume of rainfall input is significant. However, this is balanced by evaporation from the water surface. In an average year, rainfall will occur almost evenly throughout the year, but evaporation will peak in the summer months. Thus in summer there can be more evaporation than input from the two streams and rainfall; this is particularly important in drought years and may lead to negative natural inflows on some days. The simulation model needs natural inflows to Rutland.

To extend the simulations to 1930, five extended records are required:

* Orton natural flows
* Tinwell natural flows
* Pitsford natural inflows
* Eye Brook natural inflows
* Direct inflows to Rutland.

3 Extending Orton natural flows

The gauged record for Orton starts in October 1940. It has been naturalised by evaluating daily upstream abstractions and discharges and adding these to the gauged flow. Inevitably information on these artificial influences for the 1940s is limited, but during this period the artificial component of flow was small. Thus there is reasonable confidence in the natural flow record.

There are two options for extending the natural flow sequence back to 1933:

* extend the gauged flow record and naturalise this extended record
* extend the natural record itself

Extending the gauged record would require regression against another gauging station in the catchment. No Nene gauging stations existed before 1938, so this is not possible. Additionally, evaluating the artificial influences before 1940 is difficult.

Therefore it is necessary to extend the natural record, using a rainfall run-off model. The basic procedure involved is to calibrate the model against natural flows over one period and test the calibration over a second period. If the model presents an acceptable fit, it can be used to predict flows for the ungauged period.

HYRROM$^{©}$ has been used to extend the natural flow record for Orton. HYRROM is a lumped catchment hydrological model from the Institute of Hydrology, suitable for simulating flows in natural catchments. It is described by Blackie and Eeles (1985). The model consists of a series of stores representing different parts of the hydrological cycle; water flows between the stores according to model parameters. HYRROM has a built-in optimisation procedure which makes it relatively easy to calibrate.

HYRROM Version 3.0 Serial No. 126 has been calibrated for the Orton naturalised record for the period July 1942 to July 1947. Evaporation has been calculated as a sine wave with a maximum potential evaporation of 4.0 mm on 1 July, and a minimum of 0.1 mm on 1 January. Daily rainfall from Northampton Hospital (Meteorological Office Gauge Number 160206) is available from 1911 to 1986 and has been used in the simulation.

HYRROM parameter values used are:

parameter name	value
ss	5.0
rc	0.1254
rdel	1.4899
rx	1.1568
rk	0.2333
fc	0.4875
gsu	40.444
gsp	3.7791
gdel	1.7325

Table 1: HYRROM parameter values used for the simulation of natural Orton flows

The difference between gauged and simulated flow over the calibration period (July 1942 to July 1947) and over the period July 1947 to July 1952 is given in table 2.

simulated period	difference in mean flow %	days with <10% difference %	days with <20% difference %	difference in Q95 %	objective function $m^3 s^{-1}$	objective function / mean flow %
7/1942 - 7/1947	9.52	11.1	21.7	-42.8%	10.97	155.4
7/1947 - 7/1952	-13.3	8.9	19.1	10.5	9.04	122.4

Table 2: Effectiveness of HYRROM simulation of Orton flow

This simulation can not be considered to be good. The estimates of mean flow are not bad, but there is overestimation by the model during the calibration period and underestimation during the verification period. HYRROM underestimates natural Q95 during the calibration period but overestimates (by a relatively small percentage) during the verification period.

There are a number of possible reasons for these discrepancies.

- using only one rainfall station to estimate catchment rainfall
- using sine wave evaporation

- the size of the Orton catchment means that it has a complex response to rainfall; trying to model it as a single lump is possibly unreasonable

Inconsistencies in the gauged record and the naturalisation process could also lead to problems in calibration.. However, the gauged record is thought to be reasonably accurate and the naturalisation process has been applied consistently throughout the 1940s. Therefore it should be possible to create the naturalised series using a rainfall-run-off model.

Despite the potentially large errors associated with this modelling, the HYRROM simulation has been used to extend the Orton natural record back to 1933. The importance of the Orton record in Rutland yield analysis means that it is imperative that the modelling of Orton natural flows is re-evaluated and a new record is created with smaller error bands.

4 Extending Tinwell natural flows

4.1 Extending Tinwell gauged flows

The gauging station at Tinwell has operated since 1987. From 1968, Tinwell flows can be calculated from the flows at Fosters Bridge and Barrowden, which gauge 91% of the catchment. Before 1968, there is no gauging of the Welland catchment. Flows have been simulated by regression against Upton, in the Nene catchment. The regression equation represents the gauged flow well, with an r^2 value of 0.800.

Upton gauged flow is available only from November 1939. Therefore to extend the Tinwell record back to 1932 an alternative method is required. For extension of Witham gauged flows (reported in 'Reconstruction of historic Witham flows', NRA Anglian Region, July 1993), the Upton record has been extended using HYRROM. Rainfall is again from Northampton Hospital and evaporation is simulated using a sine wave peaking at 4.0 mm on 1 July, with a minimum of 0.1 mm on 1 January. Parameter values used are:

parameter name	value
ss	5.0
rc	0.1279
rdel	0.8311
rx	1.894
rk	0.1197
fc	0.4618
gsu	169.33
gsp	9.623
gdel	0.0

Table 3: HYRROM parameter values used for simulation of Upton flows

The HYRROM simulation seems to give a reasonable and consistent fit. Mean flows are slightly underestimated; Q95 is underestimated by around 40% (Table 4).

simulated period	difference in mean flow %	days with <10% difference %	days with <20% difference %	difference in Q95 %	objective function $m^3 s^{-1}$	objective function / mean flow %
1/1941 - 12/1945	-6.0	14.0	30.5	-39.0	0.858	82.4
1/1946 - 12/1950	-5.2	15.4	29.0	-38.9	1.393	118.6

Table 4: Effectiveness of HYRROM simulation of Upton flows.

There is scope for improvement in the simulation of the Upton record, especially at low flows. However, Tinwell provides a small proportion of the yield of Rutland; the use of these simulated Upton flows to produce Tinwell flows should not introduce too much error.

4.2 Naturalising Tinwell flows

The regression equations used to create Tinwell flows from Upton flows produce a flow sequence equivalent to a gauged flow in the catchment. For the period from 1940 onwards this has been naturalised to account for the impact of Eye Brook impoundment and catchment abstractions and effluent. The process used is described in 'Naturalisation of Tinwell Flows', NRA Anglian Region, December 1992. This process has been extended to cover the 1930s. There are two major components in Tinwell naturalisation; Eye Brook Reservoir impoundments and net abstractions.

4.2.1 Eye Brook impoundments

Eye Brook Reservoir impounds a tributary of the River Welland. Construction was started in 1937; the reservoir was completed in 1940 and filled for the first time in December 1940. A gauging station at the foot of the reservoir monitors outflow, which normally consists of a compensation release of 0.037 $m^3 s^{-1}$; the gauging station also measures spill from the reservoir.

The simulated Tinwell record has been created under the assumption that Eye Brook Reservoir was present in the catchment throughout the period of record. Therefore even for the period before 1940 it is necessary to naturalise Tinwell flows as though Eye Brook Reservoir had existed.

The Eye Brook flow record for 1932 to 1937 has been filled from the 1942 to 1947 record.

This is arbitrary but as summer flows from the reservoir generally consist of a constant compensation release of 0.037 $m^3 s^{-1}$ it is not unreasonable. Natural inflows to Eye Brook have been calculated as in the original work by calibration against Upton. These assumptions may lead to large inaccuracies in the estimated Eye Brook impoundment. Annually, Eye Brook impoundments are the biggest unnatural influence in the Welland catchment. However, their biggest impact is in winter; winter flows are not critical in the assessment of Rutland yield. In summer the effect is much smaller. Therefore the assumptions made about Eye Brook impoundment have relatively little impact on Rutland yield.

4.2.2 Net abstractions

The Welland catchment above Tinwell is one of the more natural catchments in the Anglian Region. Currently there is very little abstraction for public water supply; most comes from Rutland Water. Before the completion of Rutland, there must have been direct abstractions from the catchment. For the period after 1971, catchment public water supply consumption has been estimated from catchment population and per capita consumption. In the naturalisation of Tinwell flows back to 1940, the shape of the public water supply profile above Orton was used. This has been extended back to 1932 assuming linear growth. As the majority of public water supply is returned to the catchment, errors in estimating public water supply abstraction are not likely to be significant in the naturalisation.

Net agricultural abstraction for the 1930s has been assumed to be the same as during the 1940s.

Net industrial abstraction in the Welland catchment is small and was relatively constant from 1940 to 1960; the same value has been adopted for the 1930s.

The annual abstractions for each of the categories of use are given in Appendix 1.

5 Pitsford natural inflows

Pitsford is a relatively small reservoir in the Nene catchment. It is filled from its own catchment and also by pumping from the Nene at Duston Mill. Natural inflows to Pitsford are important in Rutland yield analysis as they determine the abstraction required to fill Pitsford and therefore have an influence on the volume of water reaching the Orton intake.

A method of calculating Pitsford natural inflows is described by Fawthrop (1990). A monthly reservoir water balance from 1977 to 1980 yielded a relationship with gauged flow at St Andrews Mill, on the Nene:

$$\text{inflow} = (\text{St Andrews} * 0.38) - 0.115$$

This relationship has been used in Rutland yield analysis to estimate daily inflows to Pitsford. However, the St Andrews record starts in 1939. To extend analysis back to 1932, monthly long term averages have been used to estimate Pitsford inflow. The importance of using monthly averages to estimate Pitsford inflow in Rutland yield analysis depends on the mode of operation assumed for Pitsford in the modelling. If in summer Pitsford is filled from the Nene to the licence capacity, the use of long term averages in estimating Pitsford inflows is of limited importance. However, if operation of Pitsford is optimised to limit summer pumping, the inaccuracies in natural inflows become more important. The way that Pitsford is operated is important in the estimation of Rutland yield and needs to be given further consideration.

6 Rutland natural inflows

There are three components to Rutland natural inflows:

- flow from the catchment
- direct rainfall input to the reservoir surface
- direct evaporation from the reservoir surface

6.1 Catchment flow

The direct catchment area of Rutland is around 60 km^2. Just under half of the catchment is gauged; gauging starts in November 1978, when Rutland Water started to be operational. For simulation of the operation of Rutland over the 60 years from 1932, inflows have to be calculated as though Rutland had been in existence throughout this period. Natural inflows have been related to flows at Upton on the River Nene. This inflow calculation has been extended back to 1933 using the simulated Upton record used for Tinwell flow calculation.

6.2 Direct rainfall input

For simplicity, a single raingauge record has been used to estimate direct rainfall on the surface of Rutland Water. From 1941 to 1962 Ketton (Met. Office number 153080) was used in the original work. This record actually starts in 1935. From 1933 to 1934, the rainfall record from Northampton Hospital (Met Office number 160206) has been used.

6.3 Direct evaporation

In the calculation of Rutland inflows, evaporation from the Glen catchment calculated by the Penman-Grindley method has been used. This is available from 1930 onwards, and has been used to extend Rutland inflows.

7 Impact on yield analysis

Sufficient data has been gathered to allow Rutland yield analysis by the OSAY method from January 1933 onwards. This period coincides with the analysis periods for Grafham and the Ely Ouse - Essex system; records for the Trent Witham Ancholme system have been extended back to 1933 for the same reason. 1933 has been chosen as a start date for yield analysis as it is known that the drought of 1934 to 1935 is important in the analysis of the yield of other systems.

Given the importance of the 1930s drought, analysis starting in 1933 should produce a lower yield for Rutland than analysis starting in 1942. There are many combinations of parameters that can affect Rutland yield. The results given in Table 5 have been calculated for 1992 conditions, assuming a compensation release of 5 tcmd and leakage of 9 tcmd. The OSAY method of analysis has been used, not allowing for minimum residual flow reductions at any time.

	1/1933 - 12/1992	1/1942 - 12/1992	10/1961 - 9/1991	1/1972 - 12/1992
1992 conditions	193 tcmd	238 tcmd	286 tcmd	276 tcmd

Table 5: Rutland yield for 1992 conditions

The impact of starting the analysis in 1933 using the extended records described in this document is to reduce the calculated yield considerably. The calculated yield is 45 tcmd lower than that calculated over the period 1942 to 1992, and 93 tcmd lower than that calculated over the period 1961 to 1991. The reduction is not unexpected but the magnitude is large.

Rutland yield estimation depends mainly on flow at Orton. This has been simulated by HYRROM. The fit of the simulation was not good; therefore it is necessary to evaluate the simulated flows carefully to determine the effect of errors in them.

During its calibration period, HYRROM overestimated Orton mean flow by about 10%. During the validation period, it underestimated mean flow by 13%. The minimum residual flow at Orton is 1.57 $m^3 s^{-1}$ (136 tcmd). During the 1930s, there was little net abstraction, so it is a reasonable approximation to say that when natural flows fall below about 1.6 $m^3 s^{-1}$, no abstraction to Rutland can take place. Therefore for yield calculations the quality of simulation below this level is of little importance as long as the model can distinguish that flows are below 1.6 $m^3 s^{-1}$. Above 1.6 $m^3 s^{-1}$, it is necessary to simulate flows correctly up to the pump capacity. This is about 9 $m^3 s^{-1}$; therefore the important band for flow simulation is between 1.6 and 11 $m^3 s^{-1}$. As long as the model can distinguish that flows are outside these bands, the exact flow volume is unimportant. In these bands, it is important not only to simulate the total flow volume correctly, but also to predict the timing of flows correctly. This is particularly important during summer, when the reservoir is likely to be drawn down.

band $m^3 s^{-1}$	number of days			time simulated flow is within band %
	gauged & simulated in same band	simulated flow below band	simulated flow above band	
0.000 - 1.600	656	0	154	81%
1.600 - 11.000	514	148	102	67%
> 11.000	240	39	0	87%

Table 6: flow bands for calibration period for HYRROM simulation of Orton flows

band $m^3 s^{-1}$	number of days			time simulated flow is within band %
	gauged & simulated in same band	simulated flow below band	simulated flow above band	
0.000 - 1.600	443	0	115	79%
1.600 - 11.000	674	153	112	72%
> 11.000	187	173	0	52%

Table 7: flow bands for validation period for HYRROM simulation of Orton flows

Tables 6 and 7 show how well HYRROM predicted flows in different bands. When gauged flow was below 1.6 $m^3 s^{-1}$, simulated flow was also below this value around 80% of the time during both the calibration and validation periods. Therefore the HYRROM simulation seems to be quite good at predicting the periods during which abstraction would not be permitted.

For gauged flows above 11 $m^3 s^{-1}$, the prediction from HYRROM is very good during the calibration period and less good during the validation period. However, these high flows are less critical for Rutland yield than low flows.

The most important flow band for determining the yield of Rutland is between 1.6 and 11 $m^3 s^{-1}$. In both the calibration and validation periods, simulated flow is within this band about 70% of the time that gauged flow is in the band.

Therefore the HYRROM simulated flow seems to be capable of predicting flows in the correct bands. It also seems to be consistently good at this during the calibration period and the validation period. However, for reservoir yield analysis the total volume of water available for abstraction is also important. This is shown in Table 8.

	gauged flow 1.6 - 11 m^3 s^{-1} (million cubic metres)	simulated flow 1.6 -11 m^3 s^{-1} (million cubic metres)	difference %
calibration period	273.28	275.10	0.7
validation period	379.47	381.45	0.5

Table 8: total abstractable flows.

Over both the calibration and validation periods, the total volume of water simulated in flows between 1.6 and 11 m^3 s^{-1} is less than 1% more than the gauged flow between these values.

Although the complete HYRROM simulation of Orton flows is not very good, it appears that for the flows of importance in Rutland yield analysis HYRROM is performing adequately. It seems able to distinguish quite well the timing of abstractable flows, and simulates the volume of flow available for abstraction very well. Therefore this simulated flow record should be able to predict Rutland yield with reasonable accuracy; according to Table 8 it should overpredict yield very slightly.

The discussion above relates to simulated flows during the 1940s, when gauged flows are available for comparison. It is not possible to test directly the accuracy of flows during the 1930s. One indirect method of testing is to compare simulated flows with those from an adjacent gauging station which has a record for this period. The nearest gauging station with a record through the 1930s is at Denver, on the Ely Ouse. This is not an ideal location for comparison with Orton as Denver flows are heavily influenced by the effects of canalisation, irrigation and land drainage. There is no naturalised record for Denver; it has been suggested that naturalising Denver flows may not be possible. However, comparison with the Denver record may give some indication of the quality of the Orton simulated flow.

Figure 1 is a double mass plot of the extended Orton natural record and the gauged Denver record from January 1933 to December 1953. To create this, simulated Orton flows have been used from January 1933 to October 1941.

In general there is a straight line relationship between Orton natural flows and Denver gauged flows. It is not possible from this plot to distinguish the point at which the Orton record changes from simulated to gauged flows. There are variations from a straight line, especially in the summers of 1934, 1935 and 1936, but similar variations are seen in 1945 and 1949. It is not surprising that there are seasonal differences in the response of the Nene and Denver catchments. However the double mass plot does not distinguish the simulated Orton record from the gauged Orton record. A plot of cumulative flows at Orton and Denver (fig. 2) also suggests a similar pattern in the two flow records over the 20 years from 1933.

8 Conclusions

The records required for Rutland yield analysis have been extended by a variety of methods to allow yield analysis to start in January 1933. The effect of this extension on the yield of Rutland is considerable; for 1992 conditions the yield calculated 1933 to 1992 is 45 tcmd (almost 20%) lower than that calculated 1942 to 1992.

The results presented here exemplify the problems inherent in extending reservoir yield analysis to ungauged periods. Inevitably these periods will contain important droughts; if they did not, the analysis would not be extended. However well the simulated flows represent gauged flows during the calibration and validation periods, it will never be possible to check that they are correct for the ungauged period. It will always be difficult to present a convincing case that a reservoir yield based on a simulated record is correct. However, it is very important to acknowledge that the 1930s drought was more severe than any drought experienced since, and reservoir yield analysis must not ignore this fact.

The level of the reduction in reservoir yield must be questioned. The data on which it is based has been derived from a variety of sources. Even measured data for the 1930s may not be as reliable as later data. Simulated data is always open to question. For Rutland yield analysis, flows at Orton on the Nene are of most importance. The HYRROM flow simulation leaves much room for improvement. However, over the flows of importance in yield analysis, the modelled flows seem to represent gauged flows very well. Limited checking of the 1930s simulated flow suggests that in general it is reasonable. Therefore the calculated yield should be close to that which would have been obtained had a gauged record been available.

Confidence in the results would be greater if the simulated flows could be shown to represent naturalised flows more accurately. It is recommended that an attempt is made to improve the modelling of Orton and Upton flows, and that consideration is given to modelling the Welland catchment above Tinwell rather that relying on regression against Upton.

As part of their Scenario Planning and Risk Analysis work for Anglian Water, Mott MacDonald have simulated flows in the River Nene. An evaluation of the quality of the Mott MacDonald simulation may show that it is more accurate than the HYRROM simulation described here. If this is the case, it may be possible to extend this simulated record back to 1933, to allow comparison with the results presented here. However, the error analysis shows that the yield calculated using the records extended using the methods described here should be reasonably accurate. The new calculated yields indicate clearly the significance of the 1930s drought in Rutland yield analysis.

References

Blackie J R and C W O Eeles 1985. Lumped catchment models. In M G Anderson and T P Burt (eds) **Hydrological Forecasting**, 311 - 345. John Wiley.

Fawthrop N 1990. **Naturalisation of the Orton river flow record.** NRA Anglian Region.

Watts G 1992. **Naturalisation of the Orton flow record.** NRA Anglian Region.

Watts G 1992. **Natural inflows to Rutland Water.** NRA Anglian Region.

Watts G 1992. **Naturalisation of Tinwell flows.** NRA Anglian Region.

Appendix 1: Annual abstractions in the Welland catchment

WELLAND ABOVE TINWELL (TCMD)

YEAR	direct PWS	PWS consumpt	net agric	net industr
1932	3.4	2.6	0.3	1.5
1933	3.5	2.7	0.3	1.5
1934	3.6	2.8	0.3	1.5
1935	3.7	2.9	0.3	1.5
1936	3.8	3.0	0.3	1.5
1937	3.9	3.1	0.3	1.5
1938	4.0	3.2	0.3	1.5
1939	4.1	3.3	0.3	1.5
1940	4.2	3.4	0.3	1.5
1941	4.3	3.5	0.3	1.5
1942	4.4	3.6	0.3	1.5
1943	4.5	3.7	0.3	1.5
1944	4.6	3.8	0.3	1.5
1945	4.8	4	0.3	1.5
1946	4.9	4.1	0.3	1.5
1947	5.0	4.2	0.3	1.5
1948	5.1	4.3	0.3	1.5
1949	5.2	4.4	0.3	1.5
1950	5.3	4.5	0.3	1.5
1951	5.4	4.6	0.3	1.5
1952	5.6	4.8	0.4	1.5
1953	5.8	5	0.5	1.5
1954	6	5.2	.6	1.5
1955	6.2	5.4	.7	1.5
1956	6.4	5.6	.8	1.5
1957	6.6	5.8	.9	1.5
1958	6.8	6	1	1.5
1959	7	6.2	1.1	1.5
1960	7.2	6.4	1.2	1.5
1961	7.4	6.6	1.3	1.5
1962	7.6	6.8	1.3	1.5
1963	7.8	7	1.3	1.4
1964	8	7.2	1.3	1.4
1965	8.2	7.4	1.3	1.4
1966	8.4	7.6	1.3	1.4
1967	8.6	7.8	1.3	1.4
1968	8.8	8	1.3	1.4
1969	9	8.2	1.3	1.3
1970	9.2	8.4	1.3	1.3
1971	9.4	8.6	1.3	1.3
1972	9.6	8.8	1.3	1.3
1973	9.8	9	1.3	1.3
1974	10	9.2	1.3	1.2
1975	10.2	9.4	1.3	1.2
1976	10.4	9	1.3	1.1
1977	6.4	9.6	1.3	1.1
1978	3.4	9.8	1.3	1.1
1979	0.8	10	1.3	1.1
1980	0.8	10.3	1.3	1
1981	0.8	10.5	1.3	1.0
1982	0.8	10.5	1.3	0.9
1983	0.8	10.6	1.3	0.9
1984	0.8	10.6	1.3	0.8
1985	0.8	10.7	1.3	0.8
1986	0.8	10.8	1.3	0.8
1987	0.8	10.9	1.3	0.7
1988	0.8	11	1.3	0.7
1989	0.8	11.1	1.3	0.7
1990	0.8	11.2	1.3	0.7
1991	0.8	11.3	1.3	0.7
1992	0.8	11.3	1.3	0.7

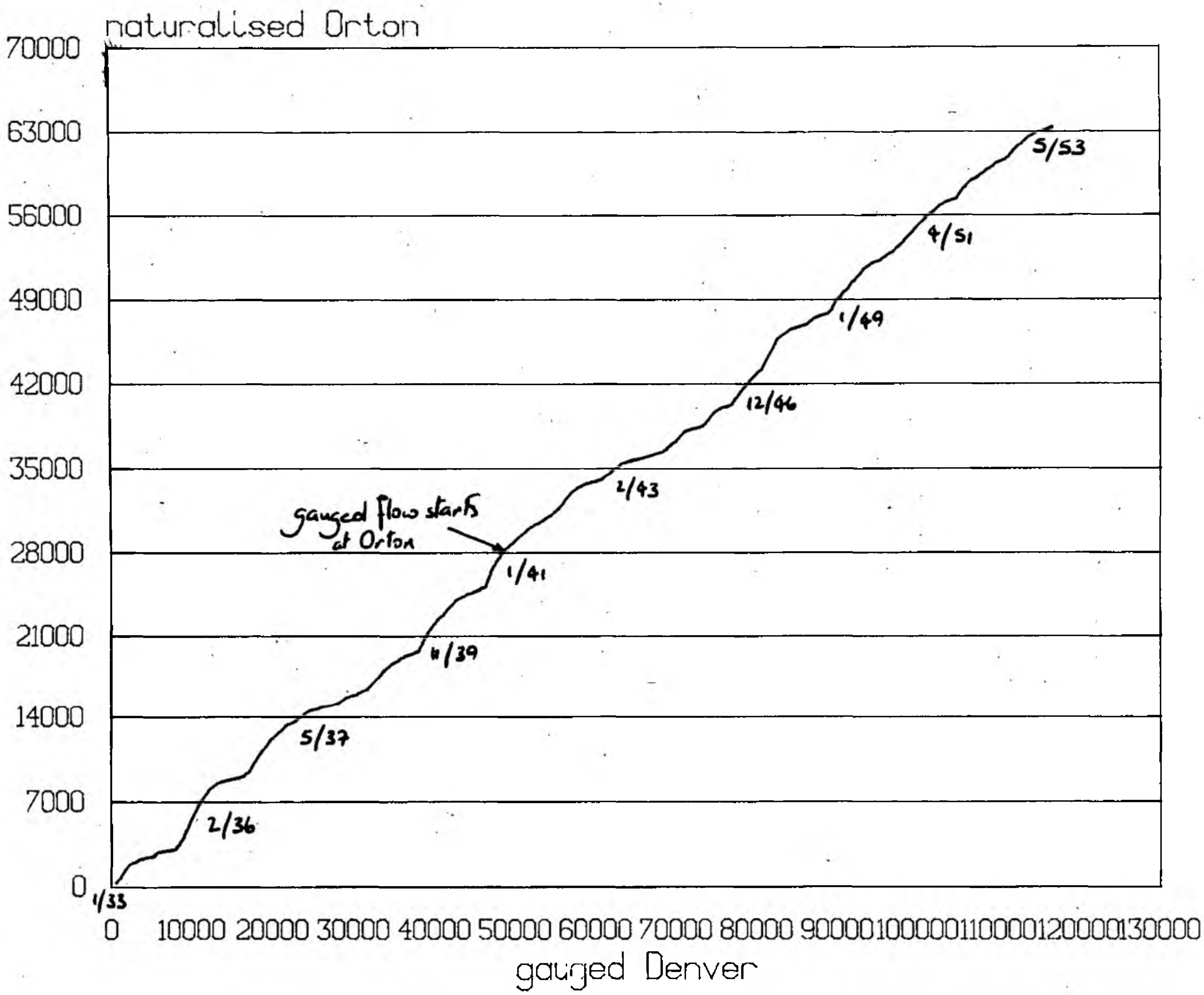

Figure 1: Double mass plot of Orton against Denver

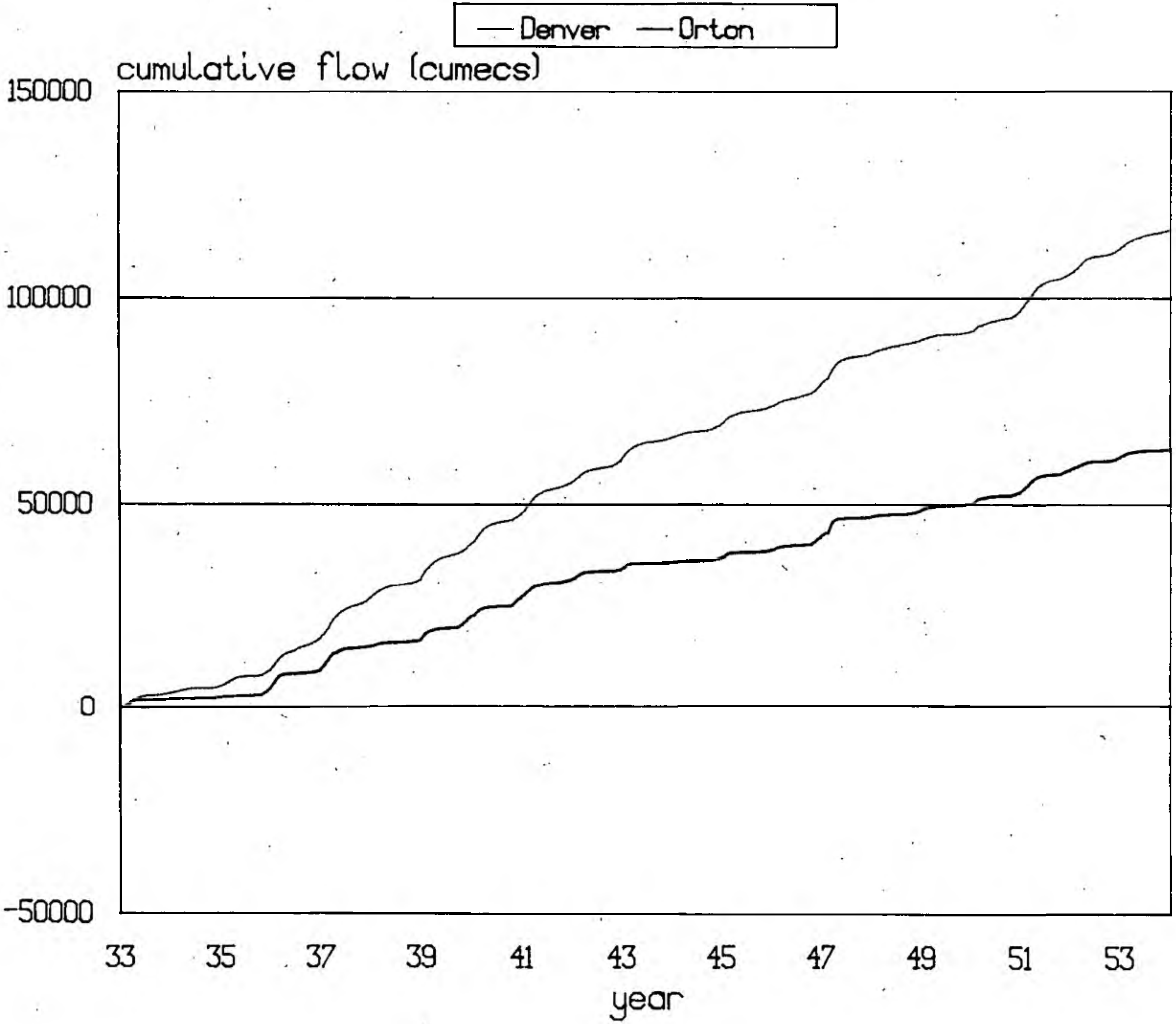

Figure 2: Cumulative flows at Orton and Denver