Environmental Protection Report

EAST DEVON PUBLIC WATER SUPPLY STRATEGY

SURFACE WATER YIELD ASSESSMENT – USE OF GENERATED LONG FLOW RECORDS

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NRA R&D Project 414 - **SURFACE WATER YIELD ASSESSMENT**

FOREWORD

The project steering group sought three examples of surface water supply systems in England and Wales to test out the initial conclusions of the research. These early conclusions suggested that 'yield' - how much you can supply during a defined drought sequence - is dependant on how sources are used and on the length of the flow sequence available for behaviour analysis.

The East Devon area was offered as a suitable example. It had a strategic reservoir 'Wimbleball' used for direct supply and river augmentation of the river Exe and a generated flow sequence back to 1856 was available for the prescribed flow point on the river Exe.

This report outlines the analysis carried out by myself and Duncan Waugh in response to the R&D project request.

Alan Weston
Water resources planning officer

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LONG FLOW RECORDS

1. Introduction

The main purpose of this report is to:

a. demonstrate the use of long flow records in estimating surface water yields during drought periods;

b. examine the effect of a change in reservoir storage capacity on available yields; and

c. study the effect of a change in drawoff on the maximum drawdown period observed during the long flow sequence.

The Water Resource Planning Model (WRPM) is used to display and record the effects. The project was undertaken on the river Exe supply system in East Devon.

2. Data

1. Thorverton G.S. - Synthetic 1856-1979

The University of East Anglia (U.E.A) produced a climate derived synthetic natural flow record for Thorverton G.S. on the river Exe for the period 1856-1979. The data was provided as mean monthly values. This sequence was then converted to daily mean flows for use with the WRPM, which requires a daily flow sequence. The flow value for each day in the month was set equal to the corresponding mean monthly flow.

2. Wimbleball Inflow Sequence - Synthetic 1856-1979

The inflow sequence to Wimbleball was created using the ratio of Average Daily Flow (ADF) at the dam site to that at Stoodleigh G.S. using the following equation:

$$\text{Wimbleball Inflow} = (Q\text{Stoodleigh} * 0.059)$$

Stoodleigh G.S. is situated upstream of Thorverton on the river Exe. To calculate the flow at Stoodleigh from that recorded at Thorverton, an equation provided in supporting documentation for a pumped storage licence application produced by South West Water Authority in 1988, entitled 'Wimbleball Pumped Storage Scheme - Hydrological Modelling', was used. This defined the ratio between flows recorded at Thorverton G.S. and Stoodleigh G.S. as being equal to

$$Q\text{Stoodleigh} = (Q\text{Thorverton} * 0.8)$$

Combining these two equations produces:

$$\text{Wimbleball Inflow} = (Q\text{Thorverton} * 0.8) * 0.059$$

This equation was then applied to every day in the synthetic flow sequence for Thorverton to produce a corresponding inflow sequence for Wimbleball.

The long flow/inflow records created were then applied to the WRPM.

3. Water Resources Planning Model (WRPM) and the Modelling Procedure

The WRPM acts as a conjunctive use model simulating the movement of water from supply sources to various demands. For this project the river Exe supply system was used. A schematic diagram of this supply system is outlined in figure 1.1. There are two main supply sources: Wimbleball reservoir and the river Exe. The demands for this supply system are direct supply from Wimbleball reservoir to Maundown water treatment works, and via either natural river flows, or river augmentation when the river flow is below the prescribed flow, to Allers and Pynes along the river Exe.

All flow/inflow data has to be read into the computer's memory, before the WRPM can operate. This acts as a limiting factor, as a PC with fresh RAM in DOS can not handle more than 44 years flow data at a time. The synthetic flow record therefore had to be split into a number of 'smaller' time sequences. This was done arbitrarily with the ease of 'splitting' the data the main consideration. As a result the following flow sequences were used:

Table 1.1

Flow Sequence - Split
1856-1899
1900-1919
1920-1939
1940-1956
1957-1979

Start-up Assumptions

A full reservoir was assumed at the start of the first sequence on January 1st 1856. For each of the remaining sequences, the storage level recorded for January 1st was deemed equal to that observed on December 31st of the previous year. A check was performed to ensure that starting with a full reservoir at the beginning of the sequence did not influence the results. This was achieved by running the sequence with an empty reservoir, of existing capacity and use from January 1st 1856. The reservoir refilled by April 1860, indicating that the initial starting volume had no effect during the subsequent major drought periods.

Modelling Process

The direct supply to Maundown was supplied all year from Wimbleball. The demands at Allers and Pynes were satisfied from the River Exe, when the daily flow was above the prescribed flow of 273 Ml/d. If the flow recorded at Thorverton dropped below this figure, releases from Wimbleball were used to supply this demand in full. For each flow sequence in turn, the amount required by the three demands were varied to calculate the total demand (drawoff) required to cause Wimbleball to fail. This effectively provided the maximum available yield from the reservoir during each flow sequence. Wimbleball was considered to fail when it was unable to supply all the demand required on any one day during the flow sequence. The year that the reservoir failed was recorded as the 'worst' drought-end year in that sequence. This operation was undertaken for each of the flow sequences outlined in table 1.1.

The process was then repeated for each flow sequence in turn, with the maximum capacity of Wimbleball altered, to observe the effect on available yield at different storage capacities. For the purposes of this project, 'demand patterns' were used to demonstrate the variations in the demand for water during the year at all three demand sites. The direct supply to Maundown used the most 'extreme' situation that Wessex Water (W.W) could impose. This involved taking the maximum licensed amount during the Summer, and a minimum during the winter. For Allers and Pynes the demand patterns applied were those observed during 1976. All three yearly demand patterns as percentages of the annual mean demand are outlined in table 1.2.

Table 1.2

Month	Maundown (W.W)	Allers demand	Pynes demand
Jan	56.9%	98%	98%
Feb	56.9%	101%	101%
Mar	56.9%	102%	102%
Apr	143.1%	103%	103%
May	143.1%	100%	100%
Jun	143.1%	114%	114%
Jul	143.1%	112%	112%
Aug	143.1%	104%	104%
Sep	143.1%	98%	98%
Oct	56.9%	89%	89%
Nov	56.9%	88%	88%
Dec	56.9%	91%	91%

These demand patterns applied to every year in the simulation. Three other factors were also incorporated within the model:

1. **Compensation Water** - 9.1 Ml/d of water was released from Wimbleball reservoir each day to supplement the flows in the river Exe.

2. **Leakage** - The amount of daily leakage from the reservoir was determined by its depth, which in turn was linearly interpolated with the daily storage value of the reservoir. The leakage was used as an additional value on top of that released as compensation water. The values used in the model are expressed in table 1.3.

3. **Evaporation** - Evaporation from the reservoir was determined from the values Sir W. Halcrows and Partners consultants suggested for the Exe-sim model. The values assumed a full reservoir all year, and that the surface area was 150 Ha.

Table 1.3

Depth	Total Leakage	Total Leakage - Compensation Flow
40m	11.23 Ml/d	2.13 Ml/d
37.5m	10.69 Ml/d	1.59 Ml/d
35.5m	10.27 Ml/d	1.17 Ml/d
33.7m	9.88 Ml/d	0.78 Ml/d
31.9m	9.48 Ml/d	0.38 Ml/d
30.1m	9.10 Ml/d	0 Ml/d

Two different demand scenarios were then studied:

3.1 Scenario 1 - Direct Supply Priority

The direct supply to Maundown was considered top priority with initially a fully licensed amount of 31.8 Ml/d. The river augmentation at the two intakes along the river Exe were set at a mean daily value to cause the reservoir to fail. When the mean daily demand required by Allers and Pynes had been reduced to a total of 0 Ml/d (at lower reservoir storage), the mean daily amount to Maundown was successively reduced.

3.2 Scenario 2 - River Augmentation Priority

This was basically the reverse of the above, with the river augmentation given top priority. The direct supply to Maundown was therefore altered first. A total mean demand of 50 Ml/d was used for the two intakes on the river Exe. The direct supply was then altered, to create a total demand figure that would cause Wimbleball reservoir to fail for a given storage volume. For some of the less serious droughts, failure would only be caused by a direct supply of greater than 31.8 Ml/d. This was also the case for an enlarged reservoir. When the direct supply had been reduced to 0 Ml/d (at lower storage capacities), the demand required via river augmentation to Allers and Pynes was then successively reduced.

4. Results

Table 1.4 and 1.5 provide a summary of the 'worst' drought year in each sequence, together with the relevant total demand to Maundown, Allers and Pynes, in Ml/d required to cause the reservoir to fail for that particular year, for scenarios 1 and 2 respectively. These results were then plotted on a graph, displaying total demand against storage. By joining these points, a series of curves could be plotted for each of the 'worst' years. It is then possible to produce the 'lowest draw-off envelope curve' for demand plus compensation water, evaporation and leakage from the reservoir. This represents the 'worst' drought year in the whole synthetic record at each storage level, together with the maximum available yield, which is equivalent to the total drawoff required to cause Wimbleball to fail. These curves are presented in figures 1.2 to 1.5.

Table 1.4

Total Demand Causing Reservoir Failure in Drought Years Specified

Long Flow Results - Scenario 1

Storage 30000 Ml

1893 = 88.4 Ml/d
1976 = 110.1 Ml/d
1909 = 110.2 Ml/d
1923 = 135.5 Ml/d

Storage 21320 Ml

1976 = 73.7 Ml/d
1893 = 84.4 Ml/d
1909 = 92.2 Ml/d
1921 = 102.9 Ml/d
1949 = 134.4 Ml/d

Storage 17000 Ml

1976 = 55.6 Ml/d
1934 = 71.4 Ml/d
1870 = 77.4 Ml/d
1909 = 82.7 Ml/d
1949 = 112.4 Ml/d

Storage 15000 Ml

1976 = 47.2 Ml/d
1934 = 53.9 Ml/d
1870 = 68.4 Ml/d
1909 = 78.5 Ml/d
1949 = 103.4 Ml/d

Storage 11000 Ml

1934 = 29.8 Ml/d
1976 = 31.4 Ml/d
1870 = 44.4 Ml/d
1919 = 58.7 Ml/d
1940 = 73.9 Ml/d

Storage 8000 Ml

1934 = 25.8 Ml/d
1976 = 27.3 Ml/d
1870 = 27.9 Ml/d
1906 = 36.7 Ml/d
1940 = 44.8 Ml/d

Storage 3000 Ml

1870 = 9.5 Ml/d
1921 = 11.2 Ml/d
1976 = 13.4 Ml/d
1919 = 14.4 Ml/d
1940 = 16.6 Ml/d

Table 1.5

Total Demand Causing Reservoir Failure in Drought Years Specified

Long Flow Results - Scenario 2

Storage 30000 Ml

1893 = 82.7 Ml/d
1976 = 87.9 Ml/d

Storage 21320 Ml

1976 = 79.2 Ml/d
1893 = 82.2 Ml/d
1909 = 83.0 Ml/d
1934 = 86.1 Ml/d
1949 = 90.0 Ml/d

Storage 17000 Ml

1976 = 73.3 Ml/d
1921 = 79.4 Ml/d
1870 = 80.5 Ml/d
1909 = 81.9 Ml/d
1949 = 86.7 Ml/d

Storage 15000 Ml

1976 = 70.3 Ml/d
1921 = 72.8 Ml/d
1870 = 77.2 Ml/d
1909 = 81.4 Ml/d
1949 = 85.1 Ml/d

Storage 11000 Ml

1921 = 49.4 Ml/d
1870 = 64.1 Ml/d
1976 = 64.5 Ml/d
1919 = 68.9 Ml/d
1940 = 78.9 Ml/d

Storage 8000 Ml

1921 = 45.3 Ml/d
1870 = 53.1 Ml/d
1976 = 56.0 Ml/d
1919 = 59.7 Ml/d
1940 = 66.1 Ml/d

Storage 5000 Ml

1921 = 27.3 Ml/d
1870 = 32.6 Ml/d
1919 = 36.2 Ml/d
1976 = 44.2 Ml/d
1947 = 52.1 Ml/d

Storage 3000 Ml

1921 = 15.3 Ml/d
1870 = 18.0 Ml/d
1919 = 21.6 Ml/d
1976 = 25.2 Ml/d
1940 = 31.7 Ml/d

5. Draw-down analysis

Drawdown is the period in months during which a "full" reservoir begins to empty, until the reservoir refills to its "full" condition. The WRPM was used to simulate the maximum draw-down period in the generated record, at various demand levels. The demand patterns used are outlined in table 1.2. The reservoir, for this section, was assumed to exist at its natural capacity of 21320 Ml. Scenario 1 was used on the supply system, which involved direct supply to Maundown water treatment works from Wimbleball receiving top priority. The maximum period of drawdown recorded at various drawoff levels are outlined in table 1.6.

Table 1.6

Maximum Draw-down Period

Draw-off (Total demand)	Maximum Drawdown Period	Time in Months
31.8 Ml/d	Apr 1887 - Jan 1892	58 Months
40.0 Ml/d	Apr 1887 - Feb 1892	59 Months
51.8 Ml/d	Apr 1887 - Feb 1894	83 Months
60.0 Ml/d	Apr 1887 - Mar 1894	84 Months
73.0 Ml/d	Apr 1887 - Jan 1895	94 Months
76.0 Ml/d	Apr 1887 - Jan 1895	94 Months
77.0 Ml/d	Apr 1887 - Feb 1899	142 Months
80.0 Ml/d	Apr 1886 - Mar 1900	167 Months
83.0 Ml/d	Apr 1884 - Feb 1901	202 Months

Schematic Diagram of the River Exe Supply System

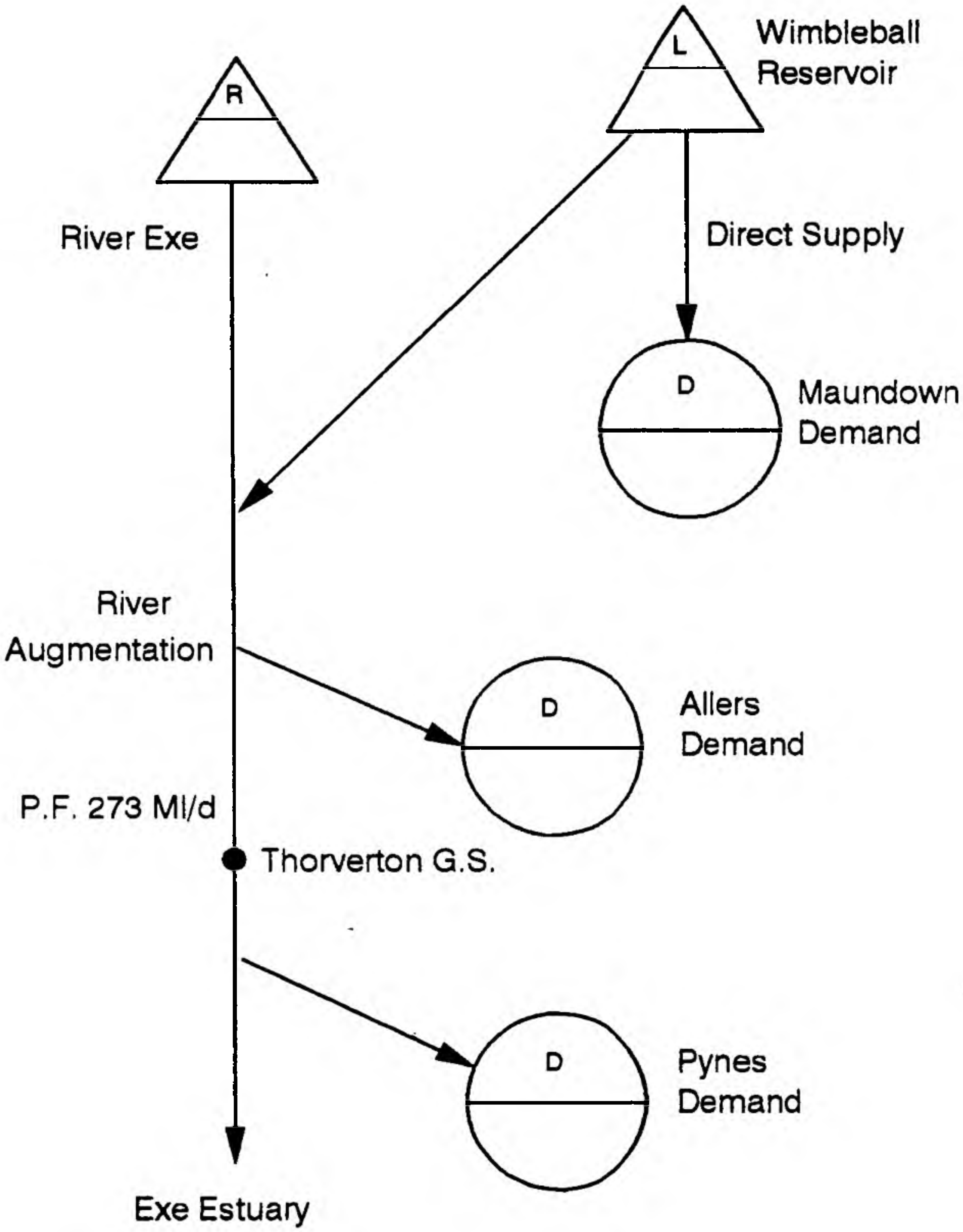


Figure 1.1

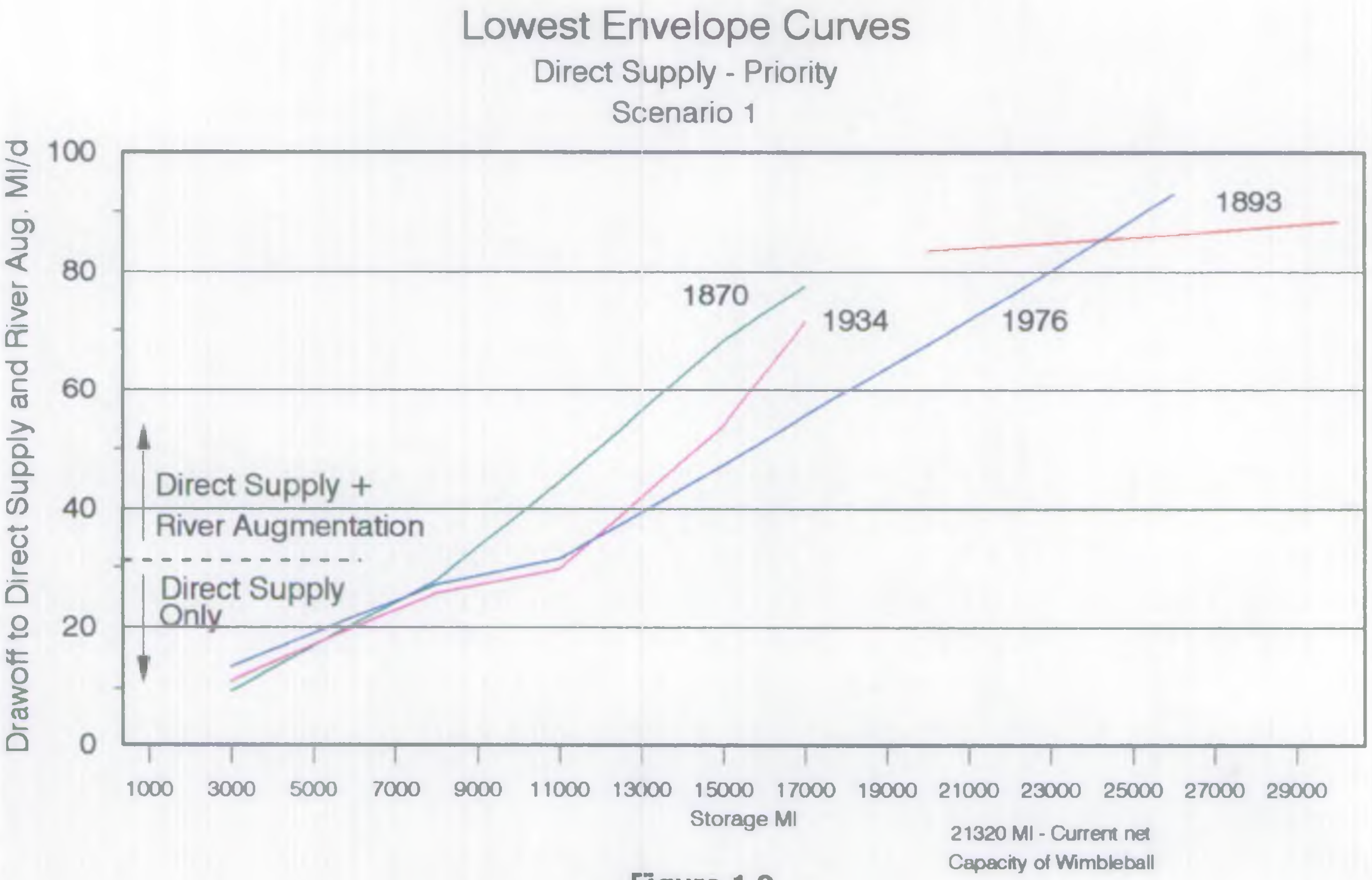
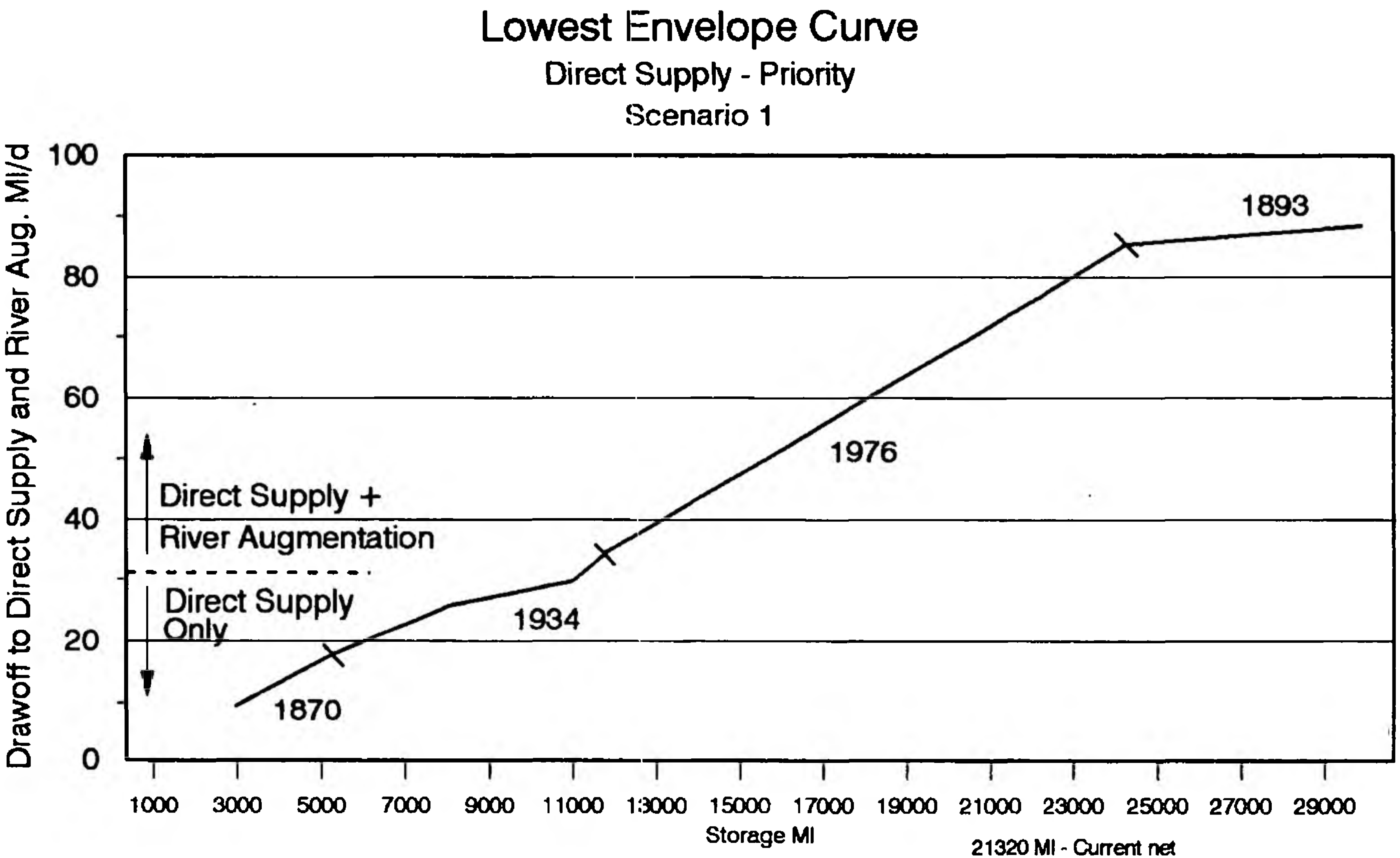
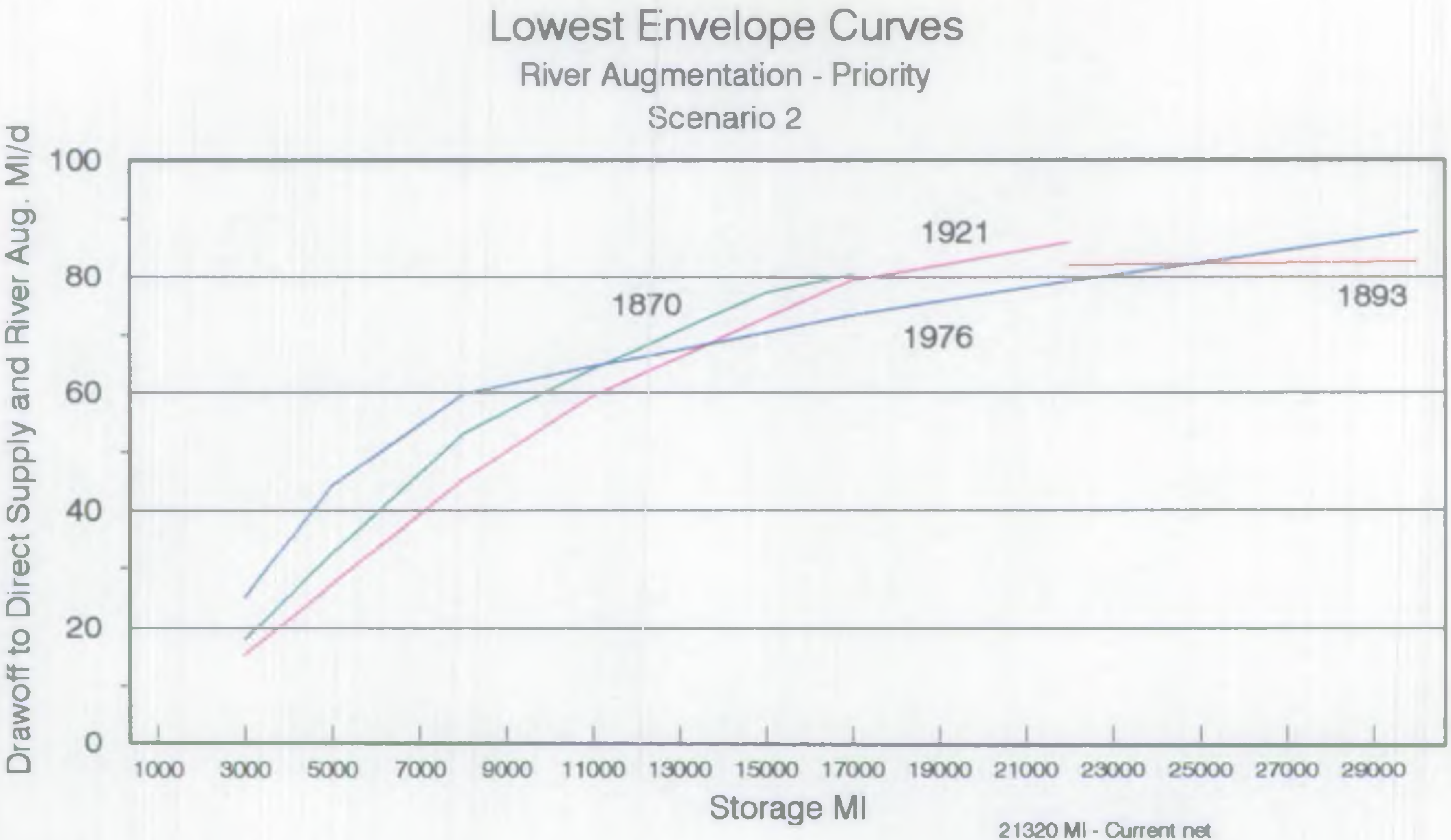

Lowest Envelope Curves
Direct Supply - Priority
Scenario 1
Drawoff to Direct Supply and River Aug. Ml/d
100
80
60
40
20
0
1000
3000
5000
7000
9000
11000
13000
15000
17000
19000
21000
23000
25000
27000
29000
Storage Ml
1870
1934
1976
1893
Direct Supply +
River Augmentation
Direct Supply
Only
21320 Ml - Current net
Capacity of Wimbleball

Figure 1.2



21320 Ml - Current net
Capacity of Wimbleball

Figure 1.3



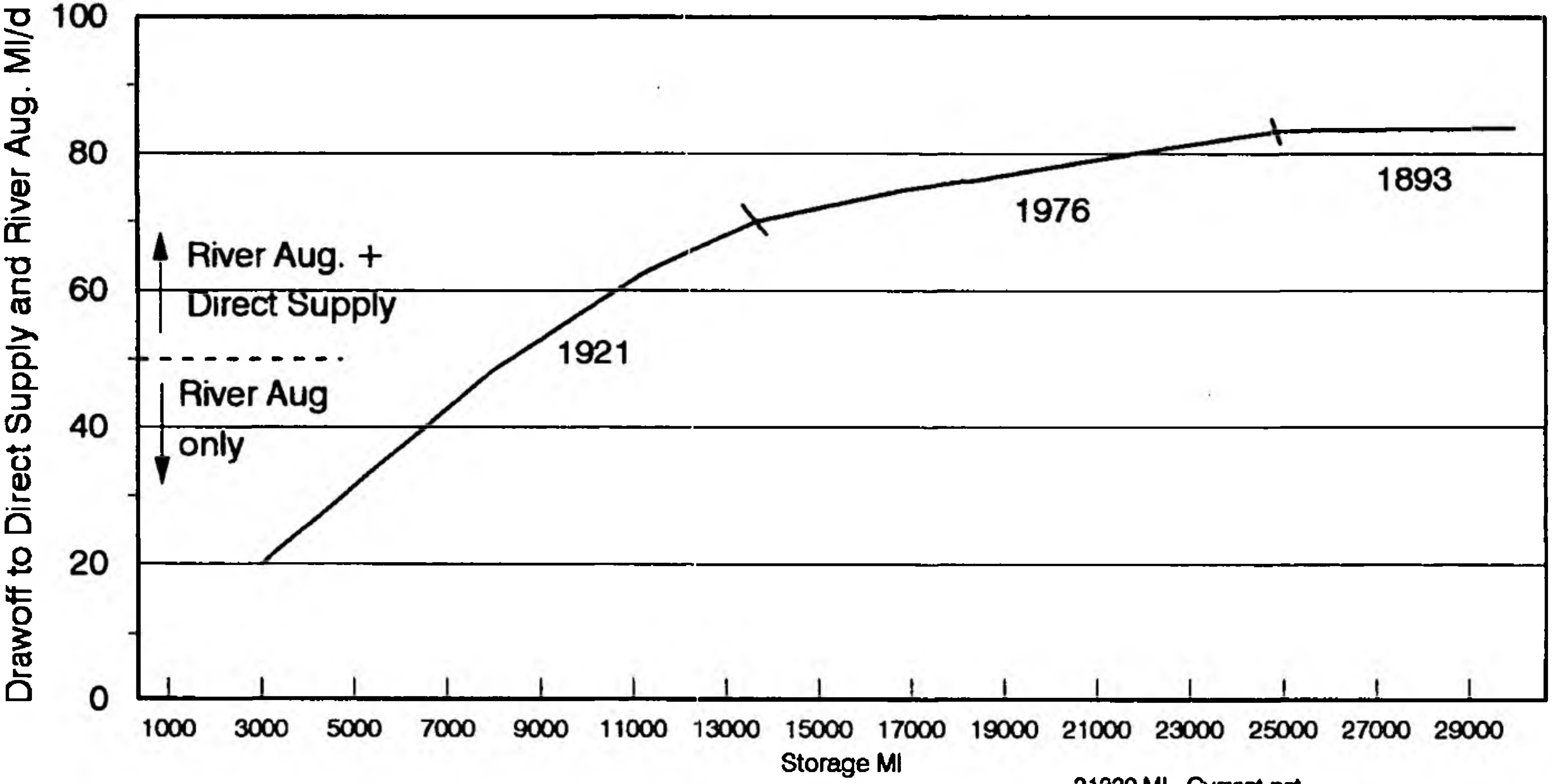
21320 Ml - Current net
Capacity of Wimbleball

Figure 1.4

Lowest Envelope Curve

River Augmentation - Priority

Scenario 2



21320 Ml - Current net
Capcity of Wimbleball

Figure 1.5

Maximum Period of Drawdown 1856-1979

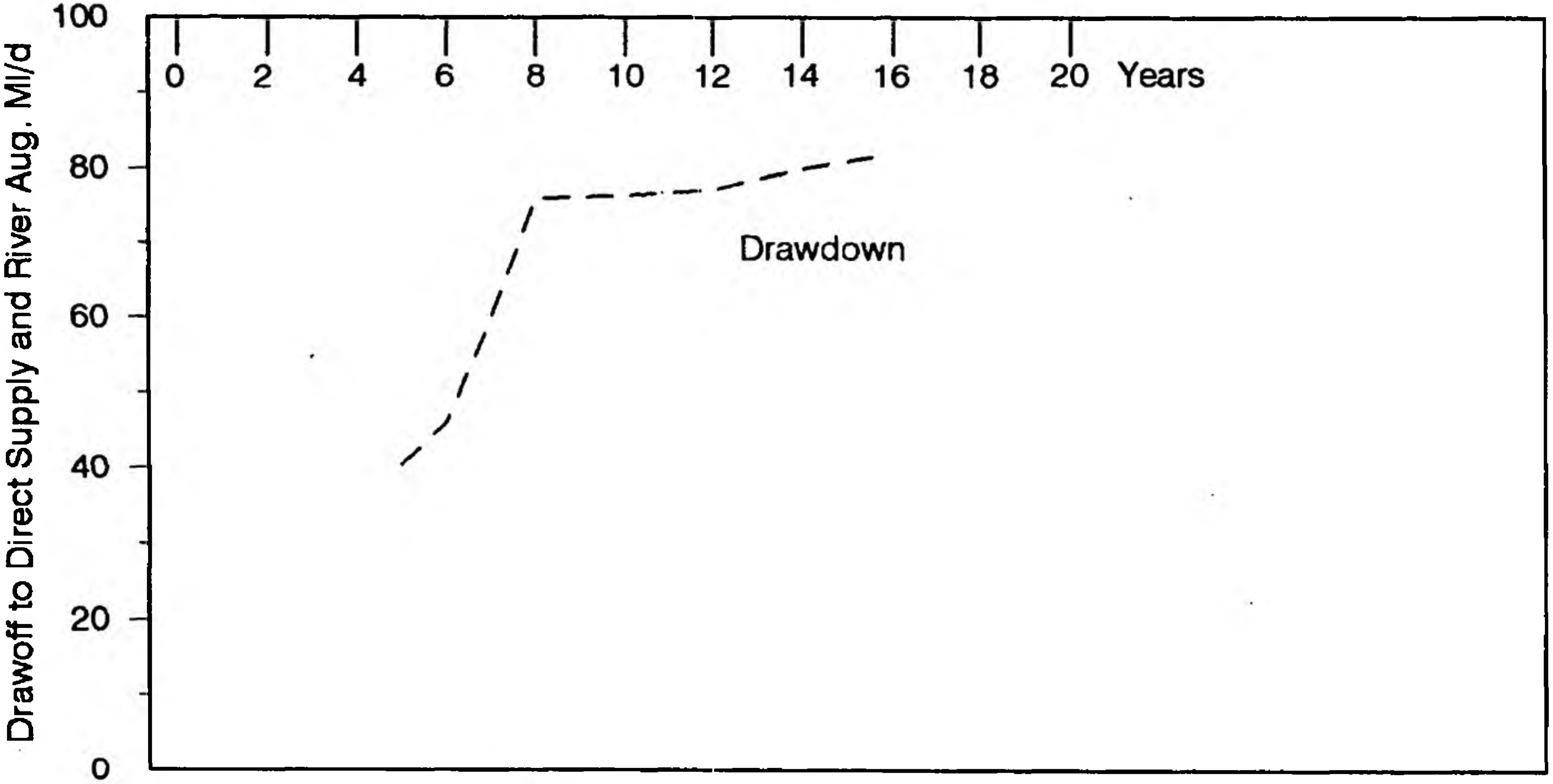


Figure 1.6

6. Conclusions:

1. The curves created for scenario 2, which involve river augmentation as the main priority, generally have a much lower gradient (figure 1.4), than those curves created for scenario 1, (figure 1.2) with a lower maximum yield value at higher storage levels, and a higher maximum yield value at lower storage levels.

2. At lower storage levels (less then 5000 Ml storage capacities) the system is single season critical producing a different worst drought year, 1870 and 1921 for scenarios 1 and 2 respectively (figures 1.3 and 1.5). At higher storage levels (5000-25000 Ml storage), the system becomes two year critical with end years of 1934 and 1976 providing the least yield for each scenario. At the highest storage levels (greater then 25000 Ml), a continual 7 year period of drawdown produces the worst drought sequence, ending in 1893.

3. At the highest storage levels (greater than 25000 Ml capacity), the lowest envelope curve becomes almost horizontal (figures 1.3 and 1.5). This results in a large increase in the reservoir's capacity producing an almost imperceptible rise in the amount of available yield during the 'worst' drought end-year of the long flow record (1893). This clearly indicates that enlarging the present Wimbleball reservoir would produce no significant gain in yield

4. The maximum period of drawdown, when displayed against drawoff, using Wimbleball reservoir at its natural capacity of 21320 Ml and scenario 1 conditions, produces a distinctive shape (figure 1.6). At lower demand levels, a relatively large increase in the amount of drawoff causes a small increase in the maximum period of drawdown. This trend continues until a 'kink' is observed at 77 Ml/d total demand, with a rapid increase in the maximum drawdown period, as a result of a very small increase in drawoff. The upper part of the drawdown curve, produces a similar shape to the 'lowest draw-off envelope curve' for the same period around 1893. This suggests that for a supply system such as the Exe, during the 'worst' drought period using a synthetically created long flow sequence, a drawoff level can be observed above which a relatively small increase in the total demand results in a large increase in the maximum drawdown period.

5. The main advantage with using long flow records, is that they allow the study of a supply system's characteristics for a longer period than measured records alone. In this project, the measured records extend back to 1956, and include the two year major drought sequence in 1976. The long flow records extend back a further 100 years, so allowing examination of a greater number and variety of drought periods, and their corresponding effects on the river supply system.