## Environmental Protection Final Draft Report

# EAST DEVON PUBLIC WATER SUPPLY STRATEGY AS ASSESSMENT OF THE HYDROLOGICAL IMPACT OF THE WIMBLEBALL PUMP STORAGE SCHEME AT KEY SITES ON THE RIVER EXE 

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## LIST OF ABBREVIATIONS

| ADF | Average Daily Elow |  |
| :---: | :---: | :---: |
| ExeSim | Computer model used by SWWSL to assess storage scheme | the impact of the pumped |
| Km | Kilometres |  |
| M1 | Mega Litres |  |
| M1/d | Mega Litres per day |  |
| cumecs | Cubic Metres per second |  |
| NRA (SW) | National Rivers Authority (South West) | . . |
| Q | Discharge |  |
| SWWSL | South West Water Services Limited |  |

Figure 18 ( $a$ and b)

Figure 19 ( a and b)

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Hydrographs Upstream and Downstream of Pynes Leat Abstraction for the Pumped Storage Scenario in 1975 and 1976.

Hydrographs Upstream of St James Weir - Tidal Limit for the Natural, Existing and Pumped Storage Scenarios in 1975 and 1976.

Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Exebridge for 1975/76.

Natural, Existing and Pumed Scenario Flow Duration Curves Upstream of Highleigh Mill Fish Farm Abstraction for 1975/76.

Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Highleigh Mill Fish Farm Abstraction for 1975/76.

Natural, Existing and Pumped Scenario Flow Duration Curves Upstream of Oakfordbridge Fish Farm Abstraction for 1975/76.

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Natural, Existing and Pumped Scenario Flow Duration Curves Upstream of Heathcoats-Tiverton Leat Abstraction for 1975/76.

Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Heathcoats-Tiverton Leat Abstraction for 1975/76.

Natural, Existing and Pumped Scenario Flow Duration Curves Upstream of Thorverton Leat Abstraction for 1975/76.

Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Thorverton Leat Abstraction for 1975/76.

Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Northbridge for $1975 / 76$.

Natural, Existing and Pumped Scenario Flow Duration Curves Upstream of Pymes Leat Abstraction for 1975/76.

Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Pynes Leat Abstraction for 1975/76.

Natural, Existing and Pumped Scenario Flow Duration Curves Upstream of St James Weir - Tidal Limit for 1975/76.

Schematic representation of Flow Accretion Profiles for the River Exe at Q95 conditions under the Natural, Existing and Pumped Storage Scenarios.

Schematic representation of Flow Accretion Profiles for the River Exe at Q50 conditions under the Natural, Existing and Pumped Storage Scenarios.

## Summary

SWWSL applied for a licence to abstract water from the River Exe at Exebridge for pump storage of Wimbleball Reservoir. As part of the determination of this application NRA SW undertook an assessment of the potential hydrological impact of the scheme at key sites on the River Exe between Exebridge and St. James Weir, the tidal limit.

The assessment considered the impact of the scheme in relation to both the natural and existing situation. The results are presented as hydrographs and flow duration curves and are described in terms of percentage changes in flow or exceedence statistics (Q50 and Q95).

Downstream of Exebridge the flows in the River Exe from January to March 1976 inclusive would be reduced by about 138 due to the abstraction. Further downstream the impact would be reduced, although downstream of Northbridge flows would be reduced by about $12 \%$ due to the increased abstraction of unsupported river water. There would, as a result of the scheme, be positive changes in the $\mathbf{Q 9 5}$ flow in comparison to the existing situation and negative changes in the Q50.

The leat abstractions, particulary those at Thorverton and Pynes have the potential to create significant deprived reaches in the main river. Although the increased release of water for public water supply under the prum storage scheme would lead to increased surmer flows in these deprived reaches, particularly at Oakfordbridge and Highleigh, the impact of the scheme is small relative to the potential impact of the leat abstractions.

This assessment has broadly confirmed the results of SWWSL study. Differences between the statistics presented by SWWSL and the NRA generally reflect the use of different assumptions in the modelling exercise.

It is recommended that the impact of the pumped storage scheme should be reassessed following further development of the scheme operating rules in the Operational Management Strategy.

It is also recommended that data is collected at the leat abstractions to define the actual flow split between the river and the leat to enable the actual impact of the leat abstractions to be quantified.

### 2.0 Licence Conditions and Operating assumptions

### 2.1 Pump Storage Scheme: Exebridge

The operating rules proposed by SWWSL in their supporting documentation Hydrological Results Scenario 3 Appendix A9 (RP-PLA-1981AO-037(01)) are listed below. These rules were used by SWWSL in the ExeSim model and have been adopted by the NRA in assessing the potential hydrological impact of the scheme.

```
Abstraction at Exebridge only if the following reservoir storage volumes
are not exceeded - Nov 6396 Ml, Dec 14924 Ml, Jan 14924 Ml, Feb 18122 Ml,
Mar 20254 Ml, Apr 21320 Ml (full), May 21320 Ml (full).
Abstraction at Exebridge during the period November to May only.
No abstraction if \(Q<100 \mathrm{Ml} / \mathrm{d}\) at Exebridge. Abstraction not to reduce flow below \(100 \mathrm{Ml} / \mathrm{d}\).
Abstraction at Exebridge only if flow is less than \(1400 \mathrm{Ml} / \mathrm{d}\)
Minimum rate of abstraction of \(10 \mathrm{ml} / \mathrm{d}\)
Maximm abstraction of \(150 \mathrm{Ml} / \mathrm{d}\)
50\% Take rule at Exebridge
Daily decision making
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These rules are not exactly the same as those that were finally licensed by the NRA. However the rules are realistic and using these made auditing SWWSL supporting documentation more straight forward.

### 2.2 Selection of Key Sites

The sites used in this assessment include the proposed pumping site at Exebridge, the public water supply abstraction at Northbridge, the large licensed non public water supply abstractions from the River Exe at Highleigh Mill, Oakfordbridge, Heathcoats-Tiverton, Thorverton leat and Pynes leat, and the tidal limit (see Figure 1). Exebridge and Northbridge were chosen for their proximity to the key public water supply abstractions. The non public water supply abstractions were selected as the sites most likely to be affected by any change in the flow regime. The tidal limit was selected because of the NRAs interest in flows to the estuary.

SWWSL also considered Exebridge, up and downstream of Highleigh Mill and Oakfordbridge Fish Farms, up and downstream of the Northbridge abstraction and the tidal limit.

Table la: Authorised abstraction quantities for other large licensed abstractions.

| Licence No. | Approx. Location | NGR | y rate | Annual rate | No. days/year at max. daily rate |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 02/1906 | Heathcoats Tiverton | SS 949138 | $\begin{aligned} & 600295 \mathrm{~m}^{3} \\ & 600 \mathrm{ml} \end{aligned}$ | $\begin{array}{r} 54545455 \mathrm{~m}^{3} \\ 54545 \mathrm{Ml} \end{array}$ | 90 |
| 02/1927 | Thorverton leat | SS 935019 | $\begin{aligned} & 247259 \mathrm{~m}^{2} \\ & 247 \mathrm{ml} \end{aligned}$ | $\begin{array}{r} 76236818 \mathrm{~m}^{3} \\ 76236 \mathrm{Ml} \end{array}$ | 308 |
| 02/1923 | Pynes | SX 917962 | $\begin{aligned} & 873930 \mathrm{~m}^{3} \\ & 873 \mathrm{Ml} \end{aligned}$ | $\begin{array}{r} 159060000 \mathrm{~m}^{\mathrm{3}} \\ 159060 \mathrm{Ml} \end{array}$ | 18 |

The annual authorised volumes prevent abstraction at the maximum daily rate for 365 days. At Heathcoats abstraction the maximum daily rate is limited to 90 days, at Thorverton its limited to 308 days and at Pynes it is limited to 18 days.

In order to assess the potential impact of the pump storage scheme on the licensed abstractions at Heathcoats-Tiverton, Thorverton leat and Pynes leat an assumption had to be made regarding the pattern of abstraction at each site over the 1975-76 design drought.

In the absence of returns data the patterns shown in Table $1 b$ were applied to distribute the abstraction over each year in the design drought sequence.

Table 1b: Abstraction periods for other large licensed abstractions.


The pattern used at each site is composed of two rates. A higher rate from,

### 3.2 Existing Flows

The existing situation represents an estimate of what flows would be if the current Wimbleball system were operated with 1991 demands. These demands are listed below:

> Maundown $23.66 \mathrm{Ml} / \mathrm{d}^{-}$
> Allers $21.11 \mathrm{Ml} / \mathrm{d}$
> Pynes $35.0 \mathrm{Ml} / \mathrm{d}$

Monthly demand patterns agreed at the Exe Hydrology sub-group, and presented in the Demand Patterns Appendix A7 (RP-PLA-1981A0-035(01)), have been applied to the data to represent seasonal demand variations.

The existing flow at each site has been calculated in a Lotus 123 spreadsheet using the appropriate equation from the list in Appendix 3. The Public Water Supply Release (PWS in Appendix 4), Bolham Abstraction (Supply Allers in Appendix 4) and Northbridge Abstraction (Supply Pynes in Appendix 4) are all taken from SWWSL Case $U$ ExeSim output reproduced in Appendix 4 of this report. Other assumptions used in the calculation include:

* constant compensation release of $9.1 \mathrm{ml} / \mathrm{d}$
* no Exe - Taw transfer
* Transmission losses allowed for in the public water supply release carry on through the system.
* Partial releases and daily decision making.
* Tiverton STW Return equal to $3.44 \mathrm{Ml} / \mathrm{d}$
* Wimbleball reservoir inflow equal to Stoodleigh naturalised flow * 0.059

These assumptions are not exactly the same as those used by SWWSL. Nevertheless, the information presented in this report is broadly comparable to that produced by SwWSL and presented in Hydrological Results Scenario 3 Appendix A9 (RP-PLA-1981A0-037(01)).

### 3.3 Pumped Storage Flows

The pumped storage flows represent an estimate of the flow that would occur if the proposed scheme were implemented and run at 2021 demand, subject to the feservoir not failing during the 1975-76 design drought. The demands are listed below.

Maundown $31.82 \mathrm{Ml} / \mathrm{d}$
Allers $27.39 \mathrm{Ml} / \mathrm{d}$
Pynes $65.5 \mathrm{Ml} / \mathrm{d}$
The demand patterns used in the analysis of the existing situation have also been applied. The proposed operating rules described in Section 2.1 of this

### 4.12 Upstream and downstream of Bighleigh Mill Fish Farm

Figure 3 presents flows for Highleigh Mill Fish Farm immediately upstream of the abstraction. The impact of the increased augmentation releases for public water supply have increased the pumped storage scenario flows above the existing and natural hydrographs in the summer months. In the winter, especially from January to March 1976 inclusive pumping at Exebridge to top up the reservoir would reduce the flow at Highleigh. At times the hydrograph representing the prumed storage scenario is $150 \mathrm{Ml} / \mathrm{d}(1.740$ cumecs) (the proposed maximum pumping rate) below the existing hydrograph. However, as Highleigh Mill is about 2 Km downstream from Exebridge and below the River Brockey the impact of the Exebridge abstraction is less at Highleigh Mill than at Exebridge itself. On average from January to March inclusive flow immediately upstream of Highleigh Mill would be 12 \% lower than the existing flow due to the proposed scheme. Conversely in July 1976 flow at Highleigh would be 49 of higher than the existing flow.

Figure 4 compares the existing flow immediately upstream of the abstraction at Highleigh Mill with the flow between the abstraction and discharge points. During the summer months the abstraction of $73.4 \mathrm{Ml} / \mathrm{d}$ ( 0.850 cumecs) significantly reduces flow in the river below the abstraction point. Indeed, in 1976 the abstraction would completely dry the reach immediately downstream for 18 days.

Figure 5 compares the pumped storage scenario flow immediately upstream of the abstraction with the flow between the abstraction and discharge points. Whilst the abstraction for the fish farm significantly reduces flow in the river immediately below the abstraction point there is flow in the deprived reach throughout the $1975 / 76$ summer and it is similar to that which would occur under natural conditions (See Figure 3).

### 4.13 Upstream and downstream of Oakfordbridge Fish Farm

Figure 6 presents flows for Oakfordbridge Fish Farm inmediately upstream of the abstraction. The impact of the increased augmentation releases for public water supply have increased the pumped storage scenario flows above the existing and natural hydrographs in the summer months. In the winter, especially from January to March 1976 inclusive pumping at Exebridge to top up the reservoir would reduce the flow at Oakfordbridge. However, as Oakfordbridge, like Highleigh Mill, is below the River Brockey the, impact of the Exebridge abstraction is less at Oakfordbridge than at Exebridge itself. On average from January to March inclusive flow immediately upstream of Oakfordbridge would be 12 \% lower than the existing flow due to the proposed scheme. Conversely, in July 1976 flow at Oakfordbridge would be $48 \frac{\mathrm{o}}{\mathrm{f}}$ higher than the existing flow.

Figure 7 compares the existing flow immediately upstream of the abstraction at Oakfordbridge with the flow between the abstraction and discharge points. During the summer months the abstraction of $104 \mathrm{ml} / \mathrm{d}$ ( 1.206 cumecs)

### 4.15 Upstream and downstream of Thorverton Leat

Figure 12 presents flows for Thorverton immediately upstream of the leat abstraction. The pumped storage scenario flows are higher than the existing and natural hydrographs in the summer months due to the increased augmentation releases. However as about 308 of the water released for augmentation is abstracted at Bolham and relatively little returns via Tiverton STW both the existing and pumped storage flows are nearer the natural hydrograph at Thorverton than at Oakfordbridge or Highleigh. As Thorverton is downstream of Tiverton STW it benefits from the STW effluent return.

Pumping at Exebridge to top up the reservoir and increased unsupported abstraction at Bolham would reduce the flow upstream of Thorverton in the winter, particularly from January to March 1976 inclusive. On average over this period flow inmediately upstream of Thorverton would be 9 of lower than the existing flow due to the proposed scheme. Conversely in July 1976 the pump storage flow at Thorverton would be $32 \%$ higher than the existing flow.

Figure 13 compares the existing flow immediately upstream of the leat abstraction at Thorverton with the flow between the abstraction and discharge points. The $104.4 \mathrm{Ml} / \mathrm{d}$ ( 1.211 cumecs) abstraction during the summer months (May-Aug) significantly reduces flow in the river below the abstraction point. The deprived reach would be dry for 22 days in 1975 and 57 days in 1976. Because of the increased abstraction in the winter ( $261.9 \mathrm{Ml} / \mathrm{d}$ ) $(3.038$ cumecs), beginning in September, the reach immediately below the abstraction would be dry in September and November 1975 and September 1976. Flow would also be significantly depleted during October, November and December 1975 and much of 1976.

Figure 14 compares the pumped storage scenario flow immediately upstream of the abstraction with the flow between the abstraction and discharge points. Whilst the abstraction for the leat still significantly reduces flow in the river immediately below the abstraction point there would, as a result of the increased augmentation release, be flow in the deprived reach throughout the May to August summer period. This flow would be similar to that which would occur under natural conditions. However, during September 1975 and September 1976 the leat would still be dry due to the larger winter abstraction (261.9 $\mathrm{Ml} / \mathrm{d})$ ( 3.038 cumecs). Thus, despite there being more water at Thorverton than at Heathcoats, the size of the abstraction is such that the river immediately below the abstraction at Thorverton would be dry for longer than at Heathcoats.

### 4.16 Downstream of Northbridge

Figure 15 presents flows for Northbridge immediately downstream of the abstraction. The increased augmentation releases for public water supply in the summer have virtually no impact on flow immediately downstream of Northbridge. The water remaining downstream of the Bolham abstraction is
depleted during the remaining winter months in 1975 and 1976.
Figure 18 compares the pumped storage scenario flow immediately upstream of the abstraction with the flow between the abstraction and discharge points. The abstraction for the leat significantly reduces flow in the river inmediately below the abstraction. As Pynes is downstream of Northbridge it does not enjoy the full benefit of the increased augmentation release under the pumped storage scenario. Consequently, the pumped storage flow is virtually the same as the existing flow in the summer and the deprived stretch would be dry for 294 days. In the event of the abstraction at Exebridge and increased abstraction of unsupported river water at Bolham and Northbridge the deprived reach would be dry for longer under the pum storage scenario than under the existing conditions.

For much of the design drought sequence there would be insufficient water in the river to meet in full the authorised quantities on the pynes licence. In reality full authorised quantities are not abstracted at Pynes and the available flow is probably split fairly evenly between the leat and the river.

### 4.18 St James Weir - Tidal Limit

Figure 19 presents flows for the tidal limit at St James Weir. The increased augmentation releases for public water supply in the summer have virtually no impact on flow at the tidal limit. The augmentation releases have been abstracted at Bolham and Northbridge. The pumped storage scenario hydrograph does however plot slightly above the existing situation hydrograph. In the Case $U$ and Scenario 3 output from ExeSim, 108 of the augmentation release is considered to meet transmission losses. In the NRA sirmilation this transmission loss is left to pass through the system. Consequently, more transmission loss water is left in the river below Northbridge following the increased augmentation release in Scenario 3.

The abstraction at Exebridge and increased abstraction of river water at Bolham and Northbridge, when flow at Thorverton is above the prescribed level, would reduce flow during the winter. Consequently the pumped storage hydrograph plots below the existing hydrograph. From January to March 1976 inclusive the pumped storage flow at St James Weir would be 8 \% lower than the existing flow. However the impact of the abstraction at Exebridge and increased unsupported abstraction at Bolham and Northbridge would be reduced at the tidal limit due to the contributions of the Rivers Culm and Creedy.
releases for public water supply compensate for the impact of the fish farm abstraction and about the same amount of water is left in the deprived reach under the pumped storage scenario as under natural conditions. Under natural conditions there are neither abstractions or discharges and all the flow is considered to be contained within the main channel.

### 4.23 Upstream and downstream of Oakfordbridge Fish Farm

Figure 23 presents flow duration curves for 1975-76 immediately upstream of Oakfordbridge Fish Farm for the natural, existing and pumped scenarios. The impact of the abstraction at Exebridge on the flow upstream of Oakfordbridge is very similar to its impact upstream of Highleigh. The abstraction at Exebridge under the pump storage scenario would cause some reduction in flow throughout the range Q10 to Q60. The largest difference between the pumped storage and existing flow duration curve would occur at approximately Q50. The 1975-76 Q50 would decrease from 4.409 cumecs to 3.800 cumecs. At the low flow end of the flow duration curve increased releases for public water supply would result in an increase in the 095 flow from 1.034 cumecs to 1.532 . cumecs. At exceedence percentiles less than 060 the existing and pumped storage flow duration curves plot below the natural flow duration curve. At exceedence percentiles greater than $\$ 60$ the existing and pumped storage flow duration curves plot above the natural curve.

The flow duration curves for the natural, existing and pumped storage scenarios immediately downstream of the fish farm abstraction are shown in Figure 24. Both the existing and the pumped storage curves have been shifted down by 1.206 cumecs ( $104 \mathrm{ml} / \mathrm{d}$ ) due to the fish farm abstraction. Under the existing situation the river immediately below the abstraction would be dry for 83 days or $11 \%$ of the time in 1975-76. The Q95 would be equivalent to 0 cumecs. Under the pumped storage scenario there would be flow in the deprived reach throughout $1975-76$ and the Q 95 would be equivalent to 0.360 cumecs. The position of the natural flow duration curve is unchanged.

The differences between the pumped storage and existing curves reflects the impact of the Exebridge abstraction. Again the largest difference occurs at approximately Q50.

At low flows the increased releases for public water supply compensate, in part, for the impact of the fish farm abstraction.

### 4.24 Upstream and downstream of Heathcoats-Tiverton Leat Abstraction

Figure 25 presents flow duration curves for 1975-76 immediately upstream of Heathcoats leat abstraction for the natural, existing and pumed scenarios. The impact of the abstraction at Exebridge on the flow upstream of Heathcoats is still evident throughout the range Q10 to Q60. The largest difference between the pumped storage and existing flow duration curve would again occur at approximately Q50. The. 1975-76 Q50 would decrease from 5.445
due to the abstraction of 1.211 cumecs ( $104.4 \mathrm{Ml} / \mathrm{d}$ ) between May to August inclusive and 3.032 cumecs ( $261.9 \mathrm{ml} / \mathrm{d}$ ) between September to April inclusive. Under the existing situation the river inmediately below the abstraction would be dry for 79 days or 11 of of the time in 1975-76. The 095 would be equivalent to 0 cumecs. Under the pumped storage scenario there would not be flow in the deprived reach throughout 1975-76. It would be dry for 42 days or $6 \%$ of the time, 37 days or $5 \%$ less than under the existing situation. However the Q 95 would still be equivalent to 0 cumecs. The position of the natural flow duration curve is unchanged.

The differences between the pumped storage and existing curves reflects the impact of the Exebridge abstraction and the net affect of the abstraction at Bolham. Again the largest difference occurs at approximately Q50. The increased releases for public water supply at low flows do not compensate for the impact of the leat abstraction. The pumped storage flow duration curve in Figure 28 plots well below the curve representing the natural situation.

### 4.26 Downstream of Northbridge

Figure 29 presents flow duration curves for the two year design drought 197576 for Northbridge, immediately downstream of the abstraction. From a comparison of the curves it is clear that the abstraction at Exebridge would have relatively little impact on the flow at-Northbridge. Between about Q10 and 060 there would be some reduction in flow due to the abstraction at Exebridge and the inćreased abstraction of river water at Bolham and Northbridge. The increased abstraction of river water causes the sag between the existing and the pumped storage curves between about Q40 and Q60. The 1975-76 Q50 flow would decrease from about 5.652 cumecs to 4.623 cumecs. At the low flow end of the flow duration curve the proposed scheme would lead to a small increase in flow compared to the existing situation. The reasons for this are outlined in Section 4.16 of this report.

### 4.27. Upstream and downstream of Pynes leat

Figure 30 presents flow duration curves for 1975-76 immediately upstream of Pynes leat abstraction for the natural, existing and pumped scenarios. The impact of the abstractions at Exebridge, Bolham and Northbridge on the flow upstream of Pynes Leat is evident throughout the range 010 to 060 . The difference between the pumped storage and existing flow duration curve is greatest in the range Q40 to Q60. The 1975-76 Q50 would decrease from 7.240 cumecs to 6.236 cumecs. At the low flow end of the flow duration curve increased releases for public water supply would, as discussed in Section 4.16 result in a relatively small increase in the $Q 95$ flow from 0.924 cumecs to 0.973 cumecs. At exceedence percentiles less than $Q 60$ the existing and pumped storage flow duration curves plot below the natural flow duration curve. At exceedence percentiles greater than $Q 60$ the pumped storage flow duration curves plot just above the existing curve.

Table 2 which is contained in the back of this report contains a list of natural, existing and pump storage Scenario 3 1975-76 Q95 and Q50 statistics for all the key sites considered in the NRA SW simulation. The zeros in the existing 095 column indicate that the river would be dry for at least 36 days during 1975-76 ( $5 \%$ of the time). There would under the pumped scenario at 095 conditions be flow in the deprived reaches at Oakfordbridge and Heathcoats where there would not be under the existing situation. However there still would not be flow in the deprived reaches at Thorverton Leat and Pynes Leat.

These statistics are based on an assessment which uses maximum possible authorised abstraction volumes at the key leat abstractions. As such it illustrates potential impact; in reality more water is likely to be left in the main river and less in the leat. However, without gauged data for the river and leat at each site actual impacts, existing and pumped, are difficult to quantify.

The differences between the Q95 and Q50 flows for both the natural and the existing situation and the pumped storage Scenario 3 for the sites assessed by NRA SW are shown as percentages in Table 3 at the back of this report. This table only includes the sites upstream of the leat abstractions at Highleigh Mill, Oakfordbridge, Heathcoats, Thorverton and Pynes. It would be meaningless to consider percentage differences in flow statistics, particularly $Q 95$, below the abstraction, when currently under existing conditions many of the deprived reaches would be dry for significant periods during 1975-76. The hatched boxes highlight sites where a statistic (Q95 in this case) would increase as a result of pump storage. In contrast the dotted shading highlights those sites where the statistic would decrease as a result of pump storage. At all 8 listed sites the $Q 95$ would increase as a result of pump storage (in comparison to the existing (2) situation). At sites in the upper catchment such as Exebridge there would almost be a $50 \%$ increase in the 1975-76 Q95. In contrast there would be a decrease in $Q 50$ (in comparison to the existing situation) at all 8 sites of between 18 and 11\%.

SWWSL considered the hydrological impacts of the scheme in terms of the natural and existing situation at a range of sites including downstream of the abstraction at Exebridge, up and downstream of Highleigh Mill and Oakfordbridge Fish Farms, up and downstream of the Northbridge abstraction and the tidal limit.

Their results were presented in a series of hydrographs and flow duration curves. The percentage change in certain key statistics such as Q50 and Q95 between the existing situation and the pumped storage Scenario 3 were also summarised for some sites in tabular form.

The percentage changes in the 1975-76 Q95 and Q50 flow between the existing and pumped storage scenario as calculated by SWWSL and NRA SW downstream of the Exebridge abstraction and downstream of the Northbridge abstraction are compared below:
7.0 References
Watson Hawksley (1993) - Wimbleball Pumped Storage Scheme Water Resources Appendix A3 Flow Naturalisation (RP-PLA-1981A0-030 to $033(01)$ ).
Watson Hawksley (1993) - Wimbleball Pumped Storage Scheme Water Resources Appendix A7 Demand Patterns (RP-PLA-1981A0-035(01)).
Watson Hawksley (1993) - Wimbleball Pumped Storage Scheme Water Resources Appendix A9 Hydrological Results Scenario 3 (RP-PLA-1981A0-037(01)).

Figure 1: Sites on the River Exe considered in the hydrological impact assessment of Wimbleball Pump Storage Proposal


Figure 2b: Hydrographs Downstream of-Exebridge for Natural, Existing and Pumped Scenarios in 1976


Figure 3b: Hydrographs Upstream of Highleigh Mill Fish Farm Abstraction for Natural, Existing and Pumped Scenarios in 1976


Figure 4b: Hydrographs Upstream and Downstream of Highleigh Mill Fish Farm Abstraction for the Existing Situation in 1976


Figure 5b: Hydrographs Upstream and Downstream of Highleigh Mill Fish Farm Abstraction for the

Pumped Storage Scenario in 1976


Figure 6b: Hydrographs Upstream of Oakfordbridge
Fish Farm Abstraction for Natural, Existing
and Pumped Scenarios in 1976


Figure 7b: Hydrographs Upstream and Downstream of Oakfordbridge Fish Farm Abstraction for the

Existing Situation in 1976


Figure 8b: Hydrographs Upstream and Downstream -of Oakfordbridge Fish Farm Abstraction for the Pumped Storage Scenario in 1976


Figure 9b: Hydrographs Upstream of Heathcoats
Leat abstraction for Natural, Existing and
Pumped Storage Scenarios in 1976


Figure 10b: Hydrographs Upstream and Downstream of Heathcoats Leat Abstraction for the Existing Situation in 1976


Figure 11b: Hydrographs Upstream and Downstream of Heathcoats Leat Abstraction for the Pumped

Storage Scenario in 1976


Figure 12b: Hydrographs Upstream of Thorverton Leat Abstraction for Natural, Existing and Pumped Storage Scenarios in 1976


Figure 13a: Hydrographs Upstream and Downstream of Thorverton Leat Abstraction for the Existing

Situation in 1975


Figure 13a: Hydrographs Upstream and Downstream of Thorverton Leat Abstraction for the Existing Situation in 1975


Figure 13b: Hydrographs Upstream and Downstream of Thorverton Leat Abstraction for the Existing

Situation in 1976


Figure 14a: Hydrographs Upstream and Downstream of Thorverton Leat Abstraction for the Pumped

Storage Scenario in 1975


Figure 14b: Hydrographs Upstream and Downstream of Thorverton Leat Abstraction for the Pumped Storage Scenario in 1976


Figure 15a: Hydrographs Downstream of Northbridge for Natural, Existing and Pumped Storage Scenarios in 1975


Figure 15b: Hydrographs Downstream of Northbridge for Natural, Existing and Pumped Storage Scenarios in 1976


- Figure 16a: Hydrographs Upstream of Pynes Leat Abstraction for Natural, Existing and Pumped Storage Scenarios in 1975


Figure 16b: Hydrographs Upstream of Pynes Leat
Abstraction for Natural, Existing and Pumped
Storage Scenarios in 1976


Figure 17a: Hydrographs Upstream and Downstream of Pynes Leat Abstraction for the Existing

Situation in 1975


Figure 17b: Hydrographs Upstream and Downstream of Pynes Leat Abstraction for the Existing Situation in 1976


Figure 18a: Hydrographs Upstream and Downstream
of Pynes Leat Abstraction for the Pumped
Storage Scenario in 1975


Figure 18b: Hydrographs Upstream and Downstream of Pynes Leat Abstraction for the Pumped

Storage Scenario in 1976


Figure 19a: Hydrographs Upstream of St James
Weir - Tidal Limit for the Natural, Existing and
Pumped Storage Scenarios in 1975


Figure 19b: Hydrographs Upstream of St James
Weir - Tidal Limit for the Natural, Existing and
Pumped Storage Scenarios in 1976


Figure 20: Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Exebridge for


Figure 21: Natural, Existing and Pumped Scenario
Flow Duration Curves Upstream of Highleigh Mill
Fish Farm Abstraction for 1975/76


Figure 22: Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Highleigh

Mill Fish Farm Abstraction for 1975/76


Figure 23: Natural, Existing and Pumped Scenario
Flow Duration Curves Upstream of Oakfordbridge
Fish Farm Abstraction for 1975/76


Figure 24: Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Oakfordbridge

Fish Farm Abstraction for 1975/76


Figure 25: Natural, Existing and Pumped Scenario
Flow Duration Curves Upstream of Heathcoats-
Tiverton Leat Abstraction for 1975/76


Figure 26: Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Heathcoats-

Tiverton Leat Abstraction for 1975/76


Figure 27: Natural, Existing and Pumped Scenario Flow Duration Curves Upstream of Thorverton Leat

Abstraction for 1975/76


Figure 28: Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Thorverton Leat Abstraction for 1975/76


Figure 29: Natural, Existing and Pumped Scenario Flow Duration Curves Downstream of Northbridge


Figure 30: Natural, Existing and Pumped Scenario Flow Duration Curves Upstream of Pynes Leat

Abstraction for 1975/76


Figure 31: Natural, Existing and Pumped Scenario
Flow Duration Curves Downstream of Pynes Leat
Abstraction for 1975/76


Figure 32: Natural, Existing and Pumped Scenario
Flow Duration Curves Upstream of St James Weir -
Tidal Limit for 1975/76


Figure 33: Schematic representation of Flow Accretion Profiles for the River Exe at Q95 conditions under the natural, existing and pumped storage scenarios.


Figure 34: Schematic representation of Flow Accretion Profiles for the River Exe at Q50 conditions under the natural, existing and pumped storage scenarios.


Table 2: Natural, Existing and Pumped Scenario Q95 and Q50 flow statistics at key sites on the River Exe

| Site | Natural |  | Existing |  | Pumped |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: |
| Q50 | Q95 | Q95 |  |  |  |  |
| Downstream of Exebridge | 0.551 | 4.381 | 0.999 | 4.091 | 1.491 | 3.467 |
| Upstream of Highleigh Mill | 0.578 | 4.589 | 1.021 | 4.314 | 1.516 | 3.670 |
| Downstream of Highleigh Mill | 0.578 | 4.589 | 0.146 | 3.410 | 0.710 | 2.837 |
| Upstream of Oakfordbridge | 0.591 | 4.700 | 1.034 | 4.409 | 1.532 | 3.800 |
| Downstream of Oakfordbridge | 0.591 | 4.700 | 0.000 | 3.276 | 0.360 | 2.561 |
| Upstream of Heathcoats | 0.761 | 5.992 | 0.946 | 5.445 | 1.385 | 4.821 |
| Downstream of Heathcoats | 0.761 | 5.992 | 0.000 | 3.752 | 0.271 | 2.955 |
| Upstream of Thorverton Leat | 0.856 | 6.434 | 1.151 | 5.924 | 1.530 | 5.240 |
| Downstream of Thorverton Leat | 0.856 | 6.434 | 0.000 | 3.389 | 0.000 | 2.844 |
| Downstream of Northbridge | 0.869 | 6.541 | 0.694 | 5.652 | 0.759 | 4.623 |
| Upstream of Pynes Leat | 1.085 | 8.166 | 0.924 | 7.240 | 0.973 | 6.236 |
| Downstream of Pynes Leat | 1.085 | 8.166 | 0.000 | 2.112 | 0.000 | 1.233 |
| Upstream of St. James Weir | 1.295 | 9.741 | 1.133 | 8.770 | 1.195 | 7.787 |

Table 3: Percentage differences between the Pumped Storage Scenario Q95 and Q50 and the Natural (1) and Existing (2) Q95 and Q50 statistics.

| Site | Q95 | Q95 | Q50 <br> (1) | Q50 |
| :---: | :---: | :---: | :---: | :---: |
| Downstream of Exebridge |  |  | -21 | 15 |
| Upstream of Highleigh Mill |  |  | -20 | -15 |
| Upstream of Oakfordbridge |  |  | -19 | -14 |
| Upstream of Heathcoats |  |  | -20 | 12 |
| Upstream of Thorverton Leat |  |  | -19 | 12 |
| Downstream of Northbridge | -13 |  | -29 | 18 |
| Upstream of Pynes Leat | -10 |  | -24 | -14 |
| Upstream of St. James Weir | -8 |  | -20 | 11 |

Appendix 1: Theoretical ADFs at gauging stations and sites of interest on the River Exe with ratios of ADF at the site to the nearest gauging station.


Appendix 2 : Naturalisation equations for Stoodleigh and Thorverton gauging stations.

## Stoodleigh gauging station.

1. $1 / 5 / 56-31 / 12 / 61$

Stoodleigh naturalised flow $=$ Thorverton naturalised flow * Ratio of theoretical ADFs.
2. $1 / 1 / 62-8 / 1 / 78$

Stoodleigh naturalised flow = Stoodleigh gauged flow.
3. $9 / 1 / 78-13 / 6 / 85$

Stoodleigh naturalised flow $=$ stoodleigh gauged flow + Wessex abstraction + change in storage of Wimbleball.
4. $14 / 6 / 85$ onwards

Stoodleigh naturalised flow $=$ Stoodleigh gauged flow + Exe-Taw transfer + Wessex abstraction + Change in storage of Wimbleball.

Thorverton gauging station.
5. $1 / 5 / 56-9 / 1 / 78$

Thorverton naturalised flow $=$ Thorverton gauged flow + Bolham abstraction - Tiverton STW return.
6. $10 / 1 / 78-14 / 6 / 85$

Thorverton naturalised flow $=$ Thorverton gauged flow + Wessex abstraction for previous .day + Bolham abstractionTiverton $5 \pi$ return + Change in storage of Wimbleball for previous day.
7. $15 / 6 / 85$ onwards

Thorverton naturalised flow $=$ Thorverton gauged flow + Exe-Taw transfer + Wessex abstrection for previous day + Bolham abstraction - Tiverton STW return + Change in storage of Wimbleball for previous day.

Appendix 3: Equations used to produce existing and prmped storage flows at sites on the River Exe.

## 1. Downstream of Exebridge

Existing flow = Natural flow - Wimbleball inflow + PWS release + Compensation release.

Pumped Storage flow $=$ Natural flow - Wimbleball infiow + PWS releasePumping abstraction + Compensation release.

## 2. Upstream of Highleigh Fish Farm

Existing flow $=$ Natural flow - Wimbleball inflow + PWS release + Compensation release.

Pumped Storage flow ${ }^{-}=$Natural flow - Wimbleball inflow + PWS releasePumping abstraction + Compensation release.

## 3. Upstream of Oakfordbridge Fish Farm

Existing flow = Natural flow - Wimbleball inflow + PWS release + Compensation release.

Pumped Storage flow $=$ Natural flow - Wimbleball inflow + FWS releasePumping abstraction + Compensation release.
4. Tiverton - upstream of Heathcoats abstraction.

Existing flow = Natural flow - Wimbleball inflow + PWS release - Bolham abstraction + Compensation release.

Pumped Storage flow $=$ Natural flow - Wimbleball inflow + PWS releasePumping abstraction - Bolham abstraction + Compensation release.
5. Upstream of Thorverton leat

Existing flow = Natural flow - Wimbleball inflow + PWS release - Bolham abstraction + Tiverton return + Compensation release.

Pumped Storage flow $=$ Natural flow - Wimbleball inflow + PWS releasePumping abstraction - Bolham abstraction + Tiverton return + Compensation release.

## 6. Downstream of Northbridge

Existing flow $=$ Natural flow - Wimbleball inflow + PWS release - Bolham abstraction - Northbridge abstraction + Tiverton return + Compensation release.

Pumped Storage flow = Natural flow - Wimbleball inflow + PWS releasePumping abstraction - Bolham abstraction - Northbridge abstraction + Tiverton return + Compensation release.

## 7. Upstream of Pynes leat

Existing flow = Natural flow - Wimbleball inflow + PWS release - Bolham abstraction - Northbridge abstraction + Tiverton return + Compensation release.

Pumped Storage flow = Natural flow - Wimbleball inflow + PWS releasePumping abstraction - Bolham abstraction - Northbridge abstraction + Tiverton return + Compensation release.
8. St. James Weir - Tidal Limit

Existing flow $=$ Natural flow - Wimbleball inflow + PWS release - Bolham abstraction - Northbridge abstraction + Tiverton return + Compensation release.

Pumped Storage flow $=$ Natural flow $=$ Wimbleball inflow + PWS releasePumping abstraction - Bolham abstraction - Northbridge abstraction + Tiverton return + Compensation release.

## Appendix 4: SWWSL ExeSim Case U Output

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WIMBLEBALL INFLOW ADJUSTMENTS

|  | Unadjusted <br> WimbInflow | Storage Res Area |  |
| :--- | :---: | ---: | ---: | ---: |
| $20-J U N-1976$ | 0.132 | 9804 | 1.07 |
| $21-J U N-1976$ | 0.082 | 9766 | 1.068 |
| $22-J U N-1976$ | 0.068 | 9689 | 1.068 |
| $23-J U N-1976$ | 0.058 | 9620 | 1.065 |
| $24-J U N-1976$ | 0.051 | 9532 | 1.06 |
| $25-J U N-1976$ | 0.046 | 9452 | 1.06 |
| $26-J U N-1976$ | 0.043 | 9372 | 1.055 |
| $27-J U N-1976$ | 0.04 | 9291 | 1.04 |
| $28-J U N-1976$ | 0.035 | 9209 | 1.03 |
| $29-J U N-1976$ | 0.033 | 9127 | 1.02 |
| $30-J U N-1976$ | 0.034 | 9045 | 1 |


| Flow | Digect | Adjusted | Diff |  |
| :---: | :---: | :---: | :---: | :---: |
| Reduction Rainfali | Wimb Flow |  |  |  |
| 0.127 | 0.00716 | 0.134 | 0.002 | 0.19758 |
| 0.079 | 0.00444 | 0.083 | 0.001 | 0.12251 |
| 0.065 | 0.00368 | 0.069 | 0.001 | 0.10159 |
| 0.056 | 0.00313 | 0.059 | 0.001 | 0.08641 |
| 0.049 | 0.00274 | 0.052 | 0.001 | 0.07562 |
| 0.044 | 0.00247 | 0.047 | 0.001 | 0.06821 |
| 0.041 | 0.0023 | 0.044 | 0.001 | 0.06346 |
| 0.039 | 0.00211 | 0.041 | 0.001 | 0.05819 |
| 0.034 | 0.00183 | 0.036 | 0.001 | 0.05043 |
| 0.032 | 0.00171 | 0.034 | 0.001 | 0.04709 |
| 0.033 | 0.00172 | 0.035 | 0.001 | 0.04756 |
| . |  |  | 0.032 | $0.03214-$ |





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