# Resilience of SSW Water Supply System

10 August 2017

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# Contents

# 1 Introduction

## 1.1 Background

As part of its 2019 Water Resources Management Plan (WRMP), South Staffordshire Water (SSW) need to assess the resilience of their water supply system, with a focus on:

- The response of the supply system to more severe droughts than those observed in the historical record (hereafter referred to as synthetic droughts); and
- The potential impact of climate change on the deployable output (DO) of its water sources.

The preferred method of assessment was to model the water supply system using Aquator software. This required a number of input data, described in the following reports:

- Hydrology update of the Blithe (Mott MacDonald, 2017a): improved HYSIM flow series obtained using a better understanding of the Blithe hydrology.
- Aquator model update (Mott MacDonald, 2017b): development of the Aquator model from version HLA 3.02 to MM4.3.7.
- Synthetic droughts (Mott MacDonald, 2017c): definition and derivation of 6 synthetic drought scenarios for use in Aquator.
- Climate change (Mott MacDonald, 2017d): definition of 20 climate change scenarios and derivation of flows for both 2030s and 2080s for use in Aquator.

## 1.2 Objectives

The objective of this study was to use the 40 sets of climate change flow series and 6 synthetic drought series to obtain DO values for the No Restrictions (NR) and Level of Service (LOS) approaches, and compare them with the baseline to infer the resilience of the system. This includes the following tasks:

- For the climate change and synthetic drought scenarios;
  - Input the relevant flow, rainfall, PET, demand to supply and resource state series into the Aquator database;
  - Model each scenario for the NR approach to demand savings;
  - Model a selection of scenarios for the LOS approach to demand savings (for the Climate Change scenarios only);
  - Provide DO values for the modelling undertaken; and
- Report on the work undertaken.

# 2 Climate change

The climate change scenarios have been selected from the full set of 10,000 scenarios produced by UKCP09, to align with the scenarios selected by STWL, which were initially selected for WRMP14. The same 20 scenarios have been used for this study; they are spread across the probability range using the mean change in flow between April and September in the Severn catchment as a drought indicator, but weighted towards the more severe drought end of the spectrum (Table 1). Scenario 15 represents the 50$^{th}$ percentile, however, it should not be construed as the expected or most likely outcome.

Further details of the climate change data inputs are provided in the climate change flow series report (Mott Macdonald, 2017d).

**Table 1: Scenarios and UKCP09 run identifiers**

| Scenario | Rank (%) | ID |
|---|---|---|
| 1 | 1 | 8632 |
| 2 | 2 | 9855 |
| 3 | 3 | 3111 |
| 4 | 4 | 6108 |
| 5 | 5 | 1090 |
| 6 | 6 | 2203 |
| 7 | 7 | 1345 |
| 8 | 8 | 8282 |
| 9 | 9 | 6461 |
| 10 | 10 | 684 |
| 11 | 15 | 2726 |
| 12 | 20 | 9701 |
| 13 | 30 | 3521 |
| 14 | 40 | 281 |
| 15 | 50 | 3903 |
| 16 | 60 | 2745 |
| 17 | 70 | 3306 |
| 18 | 80 | 9623 |
| 19 | 90 | 1467 |
| 20 | 95 | 8764 |

## 2.1 Scenario modelling

In order to model the climate change scenarios, the following series were updated for each model run:

- **Blithe Inflow 1 (CM1) - Blithfield upstream catchment**
- **Blithe Inflow 2 (CM2) - Blithfield downstream catchment**
- **Blithfield Reservoir (RV1) - direct rainfall to Blithfield reservoir**
- **Blithfield Reservoir (RV1) - direct evaporation from Blithfield reservoir**
- River Blithe Pumpback (AB1) - Trent at North Muskham
- Severn Inflow 1 (CM4) - Severn at Bewdley
- STWL Severn Works (DC29) - STWL supply amount
- SSW River Severn Works (AB3) - Severn flow bands

The series highlighted in **bold** were produced by Mott MacDonald (Mott MacDonald, 2017d), whilst the remaining four series were produced and provided by STWL.

This allowed the calculation of DO values for the NR and LOS approaches to demand savings.

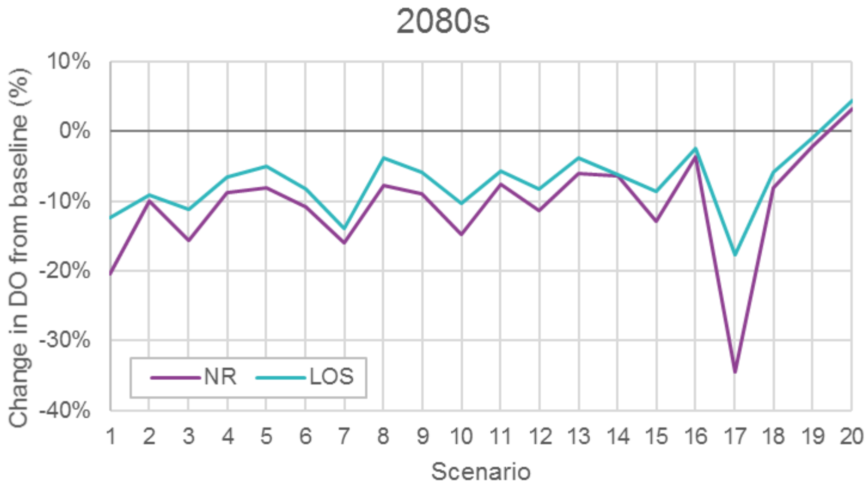
## 2.2 2080s DO results

Table 2 and Figure 1 shows the NR and LOS DO for the 2080s climate change scenarios. The 2030s results are presented in the next section; however, the analysis and interpretation was focussed on the 2080s because it has a more severe impact on the system.

**Table 2: NR DO for the 2080s climate change scenarios**

| Scenario | NR DO (Ml/d) | Percentage change from baseline | LOS DO (Ml/d) | Percentage change from baseline |
|---|---|---|---|---|
| Baseline | 333 | - | 338 | - |
| 1 | 265 | -20% | 296 | -12% |
| 2 | 300 | -10% | 307 | -9% |
| 3 | 281 | -16% | 300 | -11% |
| 4 | 304 | -9% | 316 | -7% |
| 5 | 306 | -8% | 321 | -5% |
| 6 | 297 | -11% | 310 | -8% |
| 7 | 280 | -16% | 291 | -14% |
| 8 | 307 | -8% | 325 | -4% |
| 9 | 303 | -9% | 318 | -6% |
| 10 | 284 | -15% | 303 | -10% |
| 11 | 308 | -8% | 319 | -6% |
| 12 | 295 | -11% | 310 | -8% |
| 13 | 313 | -6% | 325 | -4% |
| 14 | 312 | -6% | 317 | -6% |
| 15 | 290 | -13% | 309 | -9% |
| 16 | 321 | -4% | 330 | -2% |
| 17 | 218 | -35% | 278 | -18% |
| 18 | 306 | -8% | 318 | -6% |
| 19 | 326 | -2% | 335 | -1% |
| 20 | 344 | 3% | 353 | 4% |

**Figure 1: Change in DO from the baseline for the 2080s climate change scenarios**




The selection of scenarios undertaken by STWL was based on the mean April to September flow change in 5 exemplar catchments across the Severn basin. The initial 100 scenarios sampled form the 10000 UKCP09 projections were ranked according to this Drought Indicator and the 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 30, 40, 50, 60, 70, 80, 95, 95$^{th}$ scenario were selected. As can be seen there is a bias towards the dry end of the spectrum.

There is a broad correspondence between the increasing severity of climate change scenario and the DO results (i.e. the “dry” scenarios show the largest reductions in DO). The change in LOS DO is always less severe than that for NR. Scenario 20 is the only scenario that shows an increase in DO.

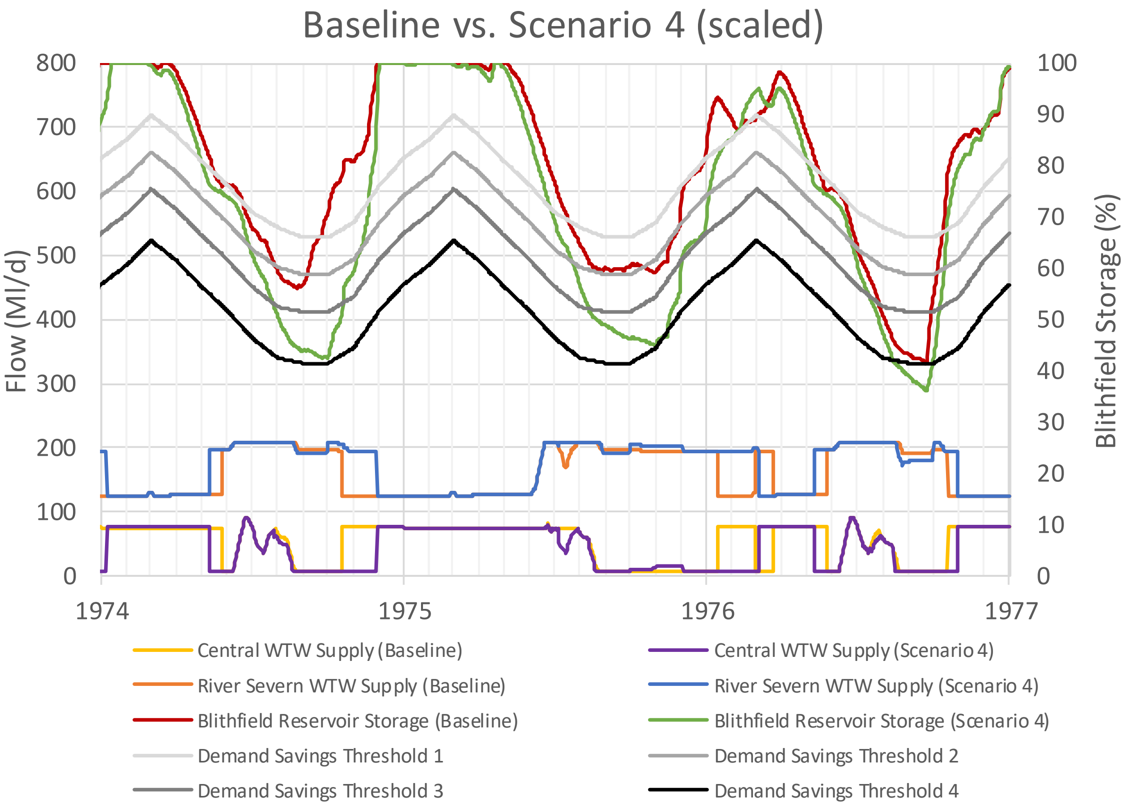
Scenario 17 is a key outlier compared to the rest of the results. This has been investigated further and winter runoff and groundwater recharge for this scenario is extremely low, which has resulted in a very low NR DO. The failure event occurs in December 1922 as a result of extremely low inflows into Blithfield reservoir. There is a similar but smaller scale effect on less severe drought events, with the result that there is a smaller change in the LOS DO (however, it is still the most severe of the 20 scenarios),

- The climate change scenarios show a decrease in NR and LOS DO for all scenarios, except scenario 20, with a maximum reduction of 35% compared to the baseline for NR scenario 17 (218Ml/d).
- If we adopt the 10, 20, 30, 40, 50, 60, 70, 80 and 90$^{th}$ scenarios as un unbiased sample (thus assuming that the STWL choice is suitable for SSW), the likely impact of CC would be a reduction of 27 and 21Ml/d for the NR and LOS DO respectively, as indicated by the median value of the 9 scenarios. If we use the 20 scenarios instead (thus assuming that all of them have initially the same potential impact), the decrease would be 29.5Ml/d for the NR DO and 21.5Ml/d for the LOS DO. Either way, CC would have a significant impact.
- Climate change would be detrimental for the system as it tends to decrease inflows to Blithfield reservoir from the Blithe and increase evaporation, the former of which is critical at times of low storage in Blithfield. An example of this is provided graphically in Figure 2 and

Figure 3, where the lower baseflow of the climate change run encourages emptying of the reservoir compared to the baseline scenario.

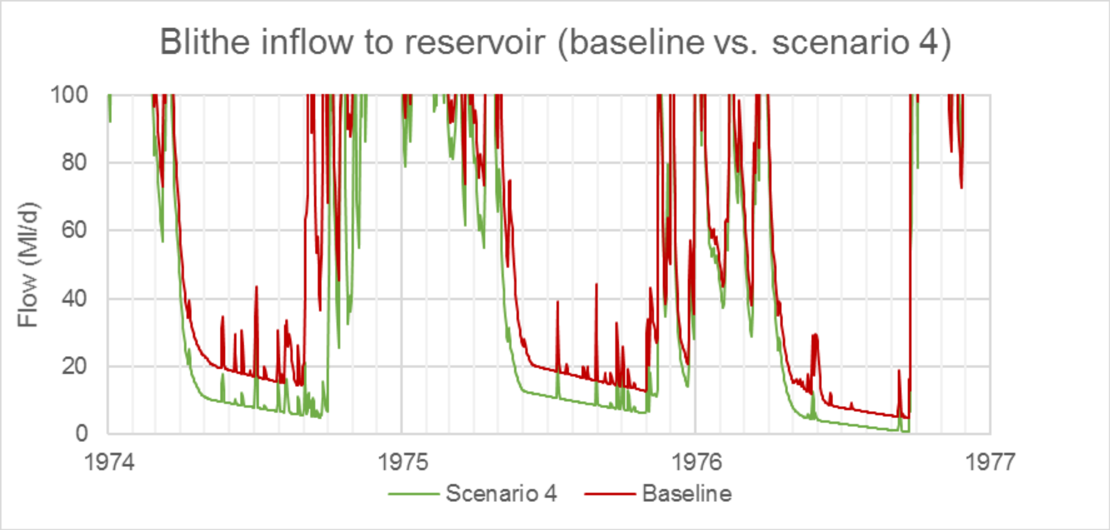
- Scenario 20 is limited by the capacity of the infrastructure (353Ml/d), meaning that DO cannot increase beyond that even though the hydrology would allow an increase.
- The LOS DO is less affected by climate change; this may be because it is defined by several drought events in the series (three hosepipe bans being allowed) and the chances of climate change affecting them in the same way and with similar magnitudes are low. As such, the maximum possible impact of the 20 climate change scenarios would be a loss of 60Ml/d in scenario 17 (278Ml/d).

**Figure 2: Evolution of Blithfield for the Baseline and Scenario 4**




Notes: Scenario 4 has had its demand scaled to match the baseline to allow for a direct comparison of the results.

**Figure 3: Blithe inflow to Blithfield reservoir for the baseline and scenario 4**



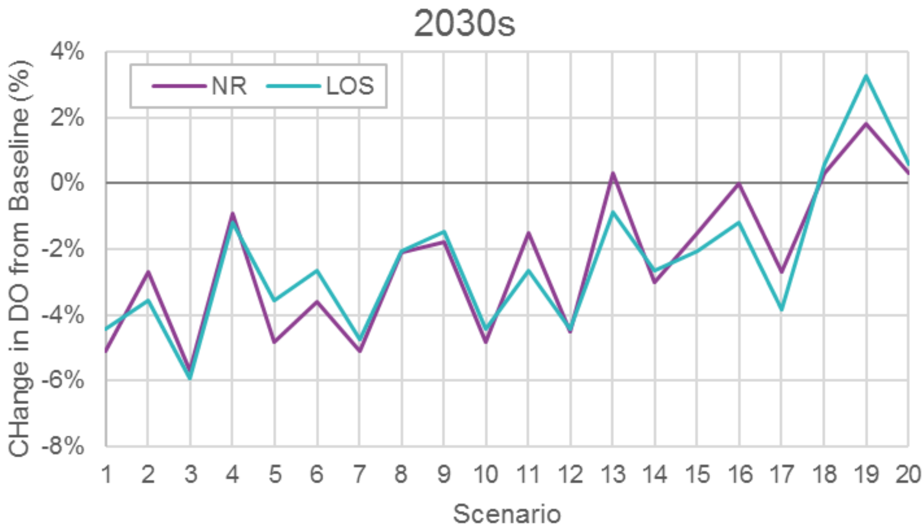

## 2.3 2030s DO Results

Table 3 and Figure 4 shows the DO results for the 2030s climate change scenarios.

**Table 3: NR DO for the 2030s climate change scenarios**

| Scenario | NR DO (Ml/d) | Percentage change from baseline | LOS DO (Ml/d) | Percentage change from baseline |
|---|---|---|---|---|
| Baseline | 333 | - | 338 | - |
| 1 | 316 | -5% | 323 | -4% |
| 2 | 324 | -3% | 326 | -4% |
| 3 | 314 | -6% | 318 | -6% |
| 4 | 330 | -1% | 334 | -1% |
| 5 | 317 | -5% | 326 | -4% |
| 6 | 321 | -4% | 329 | -3% |
| 7 | 316 | -5% | 322 | -5% |
| 8 | 326 | -2% | 331 | -2% |
| 9 | 327 | -2% | 333 | -1% |
| 10 | 317 | -5% | 323 | -4% |
| 11 | 328 | -2% | 329 | -3% |
| 12 | 318 | -5% | 323 | -4% |
| 13 | 334 | 0% | 335 | -1% |
| 14 | 323 | -3% | 329 | -3% |
| 15 | 328 | -2% | 331 | -2% |
| 16 | 333 | 0% | 334 | -1% |
| 17 | 324 | -3% | 325 | -4% |
| 18 | 334 | 0% | 340 | 1% |
| 19 | 339 | 2% | 349 | 3% |
| 20 | 334 | 0% | 340 | 1% |

**Figure 4: Change in DO from the baseline for the 2030s climate change scenarios**




Note: The x-axis has a different scale to the 2080's version of this graph in the previous section.

The 2030s climate change scenarios have the following impacts upon DO:

- There is a broad correspondence between the severity of climate change scenario and DO.
- The change in LOS DO is generally very similar to that for NR.
- Adopting an unbiased sample (10, 20, 30, 40, 50, 60, 70, 80 and 90$^{th}$ scenarios), the likely impact of CC would be a reduction of DO by 2Ml/d for NR and 5Ml/d for LOS.
- Considering all climate change scenarios, the likely impact of CC would be would be a reduction of DO by 8Ml/d for NR and 9Ml/d LOS.
- Scenario 3 offers the maximum potential impact with a decrease of 19Ml/d for NR and 20Ml/d for LOS.

The changes are much less severe than for the 2080s, even though the changes in average flow are broadly similar. This can be explained by the fact that the reduction in summer flows in the 2030s is less severe than for the 2080s.

# 3 Synthetic drought

## 3.1 Scenario modelling

In order to model the synthetic droughts scenarios the series updated for each model run were the same as for the climate change scenarios (section 2.1).

As agreed with STWL, the simulation was limited to 14 years including the selected drought. Adopting a longer run was discarded as it could alter the frequency of occurrence of droughts in comparison with the baseline, biasing the comparison of the LoS DO, which consequently has not been undertaken.

Table 4 shows the scenarios finally modelled.

**Table 4: Synthetic drought scenario summary**

| Event | Accumulation period | Scenario | Critical year | Model run period |
|---|---|---|---|---|
| 200-year | 18 | 27 | 1946 | 1939-1952 |
| | 24 | 99 | 1970 | 1963-1976 |
| | 30 | 64 | 1958 | 1951-1964 |
| 500-year | 18 | 172 | 1982 | 1975-1988 |
| | 24 | 124 | 1975 | 1968-1981 |
| | 30 | 167 | 1959 | 1952-1965 |

## 3.2 DO results

Table 5 shows the NR DO for the 6 synthetic drought scenarios.

**Table 5: NR DO for the synthetic drought scenarios**

| Event | Accumulation period (months) | Scenario | DO (Ml/d) |
|---|---|---|---|
| 200-year | 18 | 27 | 342 |
| | 24 | 99 | 319 |
| | 30 | 64 | 313 |
| 500-year | 18 | 172 | 332 |
| | 24 | 124 | 328 |
| | 30 | 167 | 311 |

While comparing with the baseline DO (333Ml/d), it can be concluded that the impact of synthetic droughts is more similar in magnitude and range to the 2030s climate change scenarios than the 2080s scenarios. The impact of the 2080s climate change scenarios on the water supply system is more severe than the synthetic droughts.

The system tends to cope well with short droughts made up of two winters and one summer (18-months), this is evident by the greater DO values for the 18-month accumulation period compared with the 24 and 30-month accumulation periods (Table 5). The evolution of Blithfield is given in Figure 5 to Figure 10. By observing the winter volume of Blithfield in the year preceding the most severe event, it is evident that the longer the drought period the less likely Blithfield is to refill during winter, and therefore is more likely to fail in the subsequent year.

The worst scenario for the system is a prolonged drought of 30 months for both the 200-year and 500-year scenarios which shows decreases in DO of 20Ml/d and 22Ml/d respectively.

For the 200-year return period, this is caused by Blithfield reservoir being drawn down earlier in the year from being full the winter before the failure event. For the 500-year return period, this is caused by Blithfield reservoir being drawn down earlier in the year from being full two years previously (as it does not refill fully in the subsequent winter). Therefore, at the beginning of spring Blithfield has a reduced volume which limits DO during the summer months.

### 3.2.1 200-year return period

**Figure 5: Scenario 27 Blithfield evolution for 1946-1952**

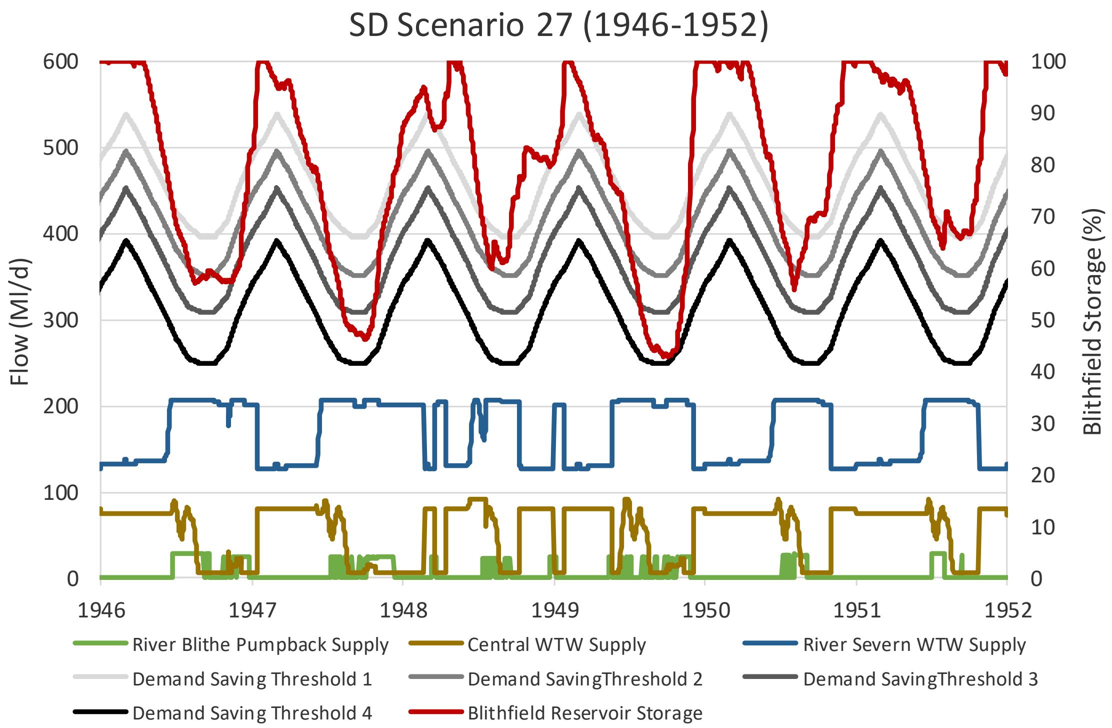


**Figure 6: Scenario 99 Blithfield evolution for 1970-1976**

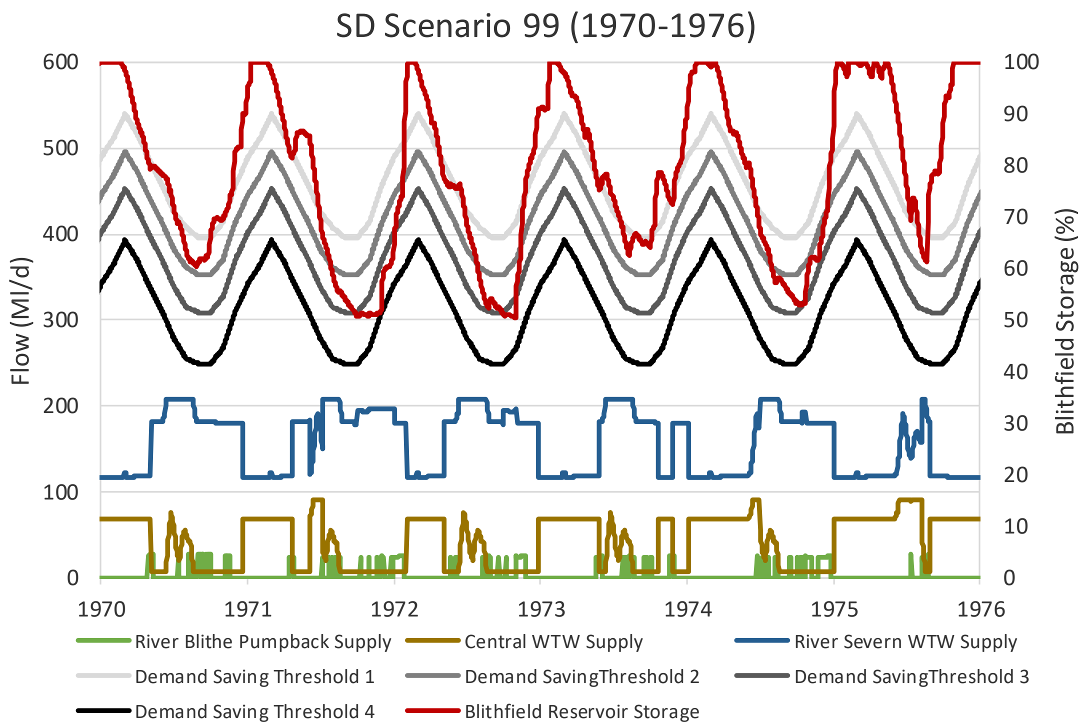
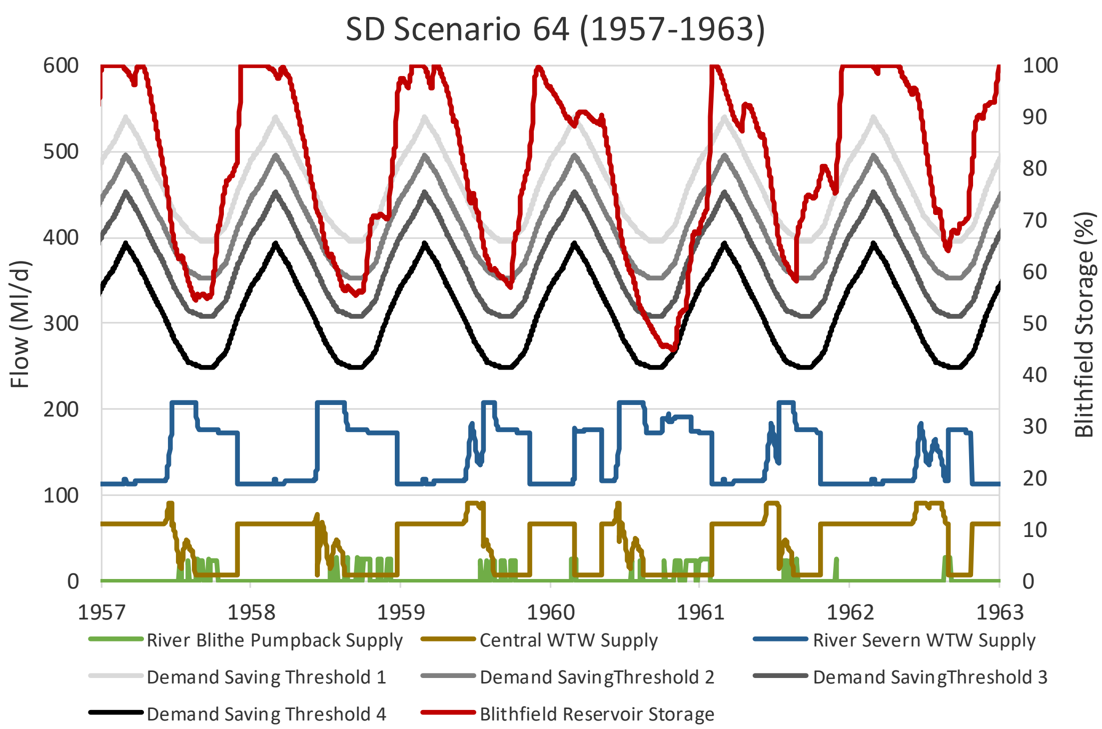



**Figure 7: Scenario 64 Blithfield evolution 1957-1963**



### 3.2.2 500-year return period

**Figure 8: Scenario 172 Blithfield evolution 1980-1986**

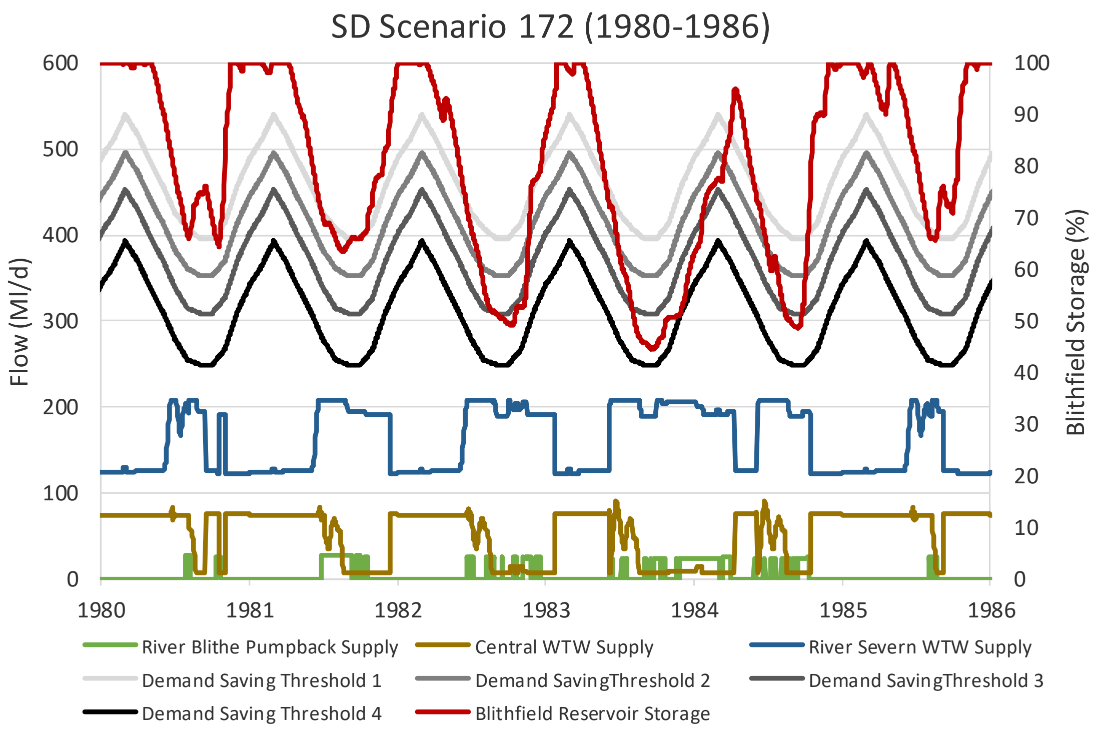



**Figure 9: Scenario 124 Blithfield evolution 1973-1979**

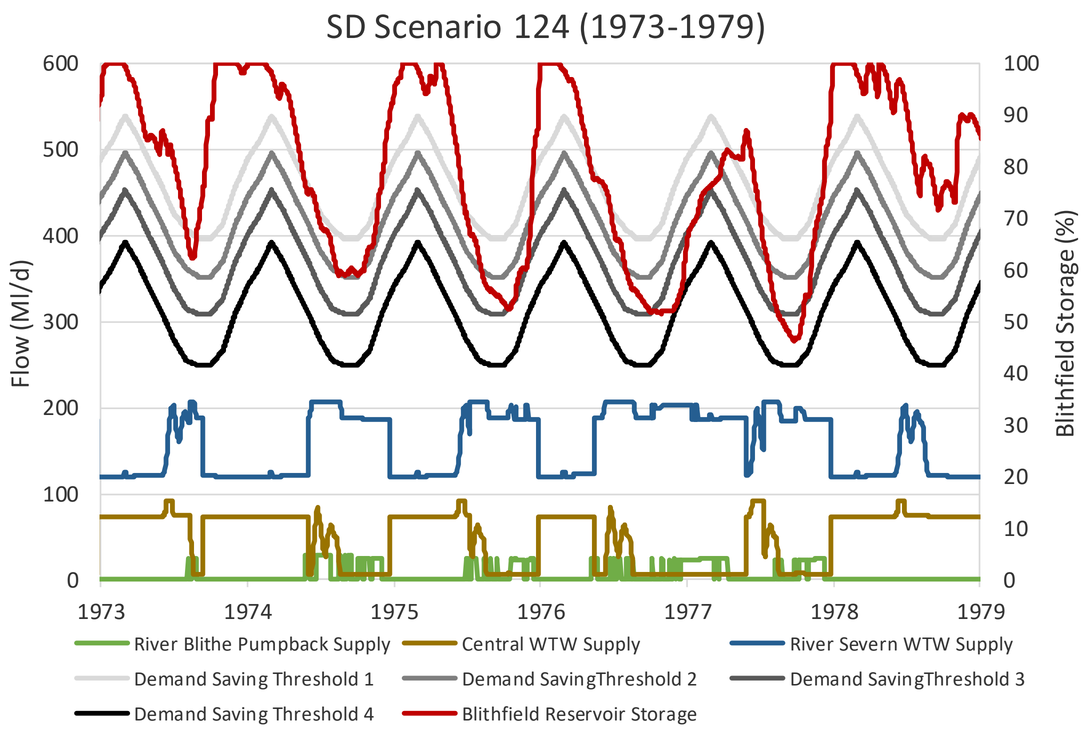


**Figure 10: Scenario 167 Blithfield evolution 1958-1963**

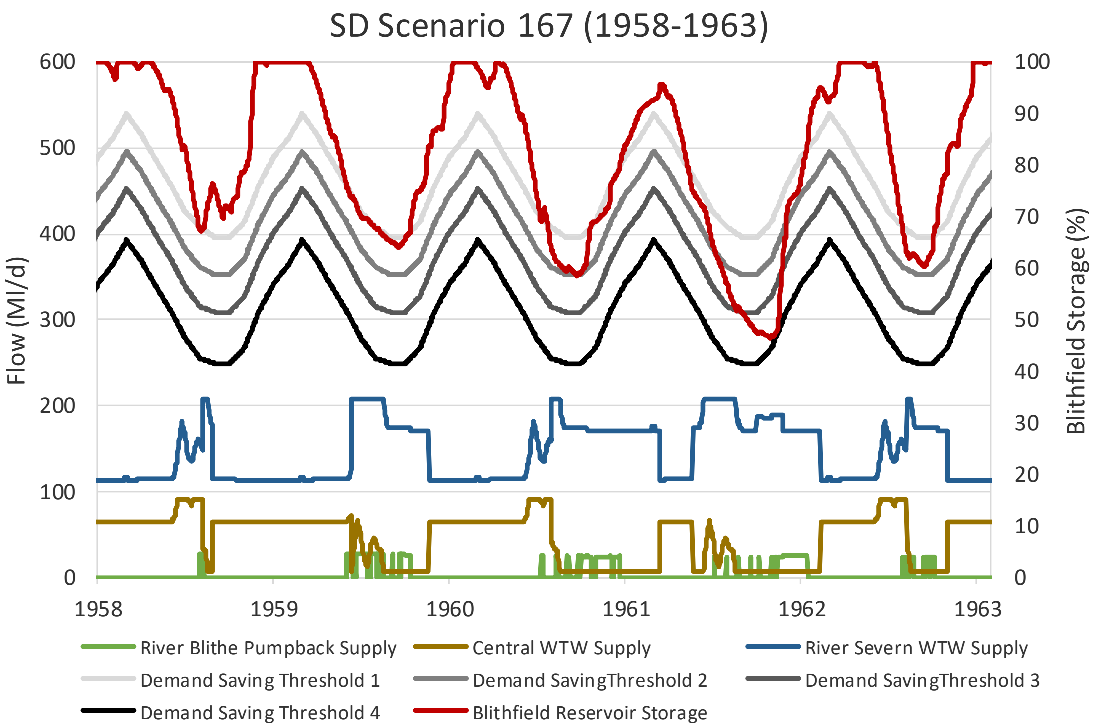
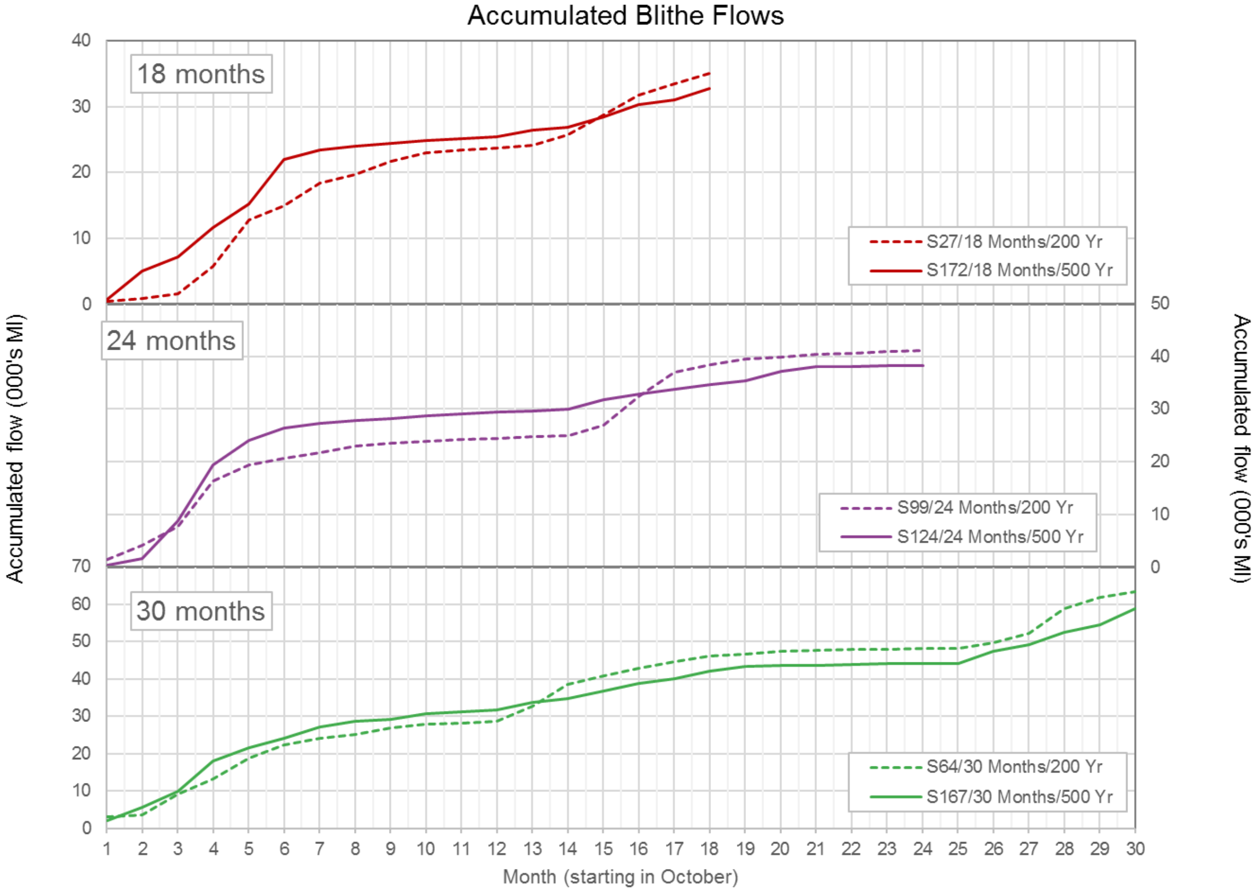



Figure 11 shows the monthly accumulated flows of the Blithe for all 6 scenarios. The final accumulated value is greater for all of the 200-year scenarios compared to the 500-year scenarios. However, the second winter (months 12 to 16) for the 200-year return periods tends to be wetter than the 500-year. This is identified by the step increase in flows for the 200-year return periods from below the 500-year curve to above it.

The 500-year and 24-month scenario (scenario 124) leads to a smaller DO loss than the 200-year and 24-month scenario (Scenario 99). This is likely to be explained by the existence of a shorter more critical drought period in the latter. (It should be noted that the critical duration for the system is not necessarily equal to one of the predefined durations.) Figure 11 shows that for the 24-month period, the 200-year flow is less than the 500-year up to 16 months. This is likely to have impacted upon the DO. A similar trend is evident in the 18-month and 30-month series, however, depending at what point level 4 event at Blithfield occurs will depend whether the lower flows for the 200-year return period will have limited the DO.

**Figure 11: Accumulated Blithe flows for the 6 scenarios**



# 4 Summary

The 20 climate change scenarios produced for each of the 2030s and 2080s, and 6 synthetic drought scenarios, have been used to provide inputs to the SSW Aquator v4.3.7 model.

The results from the climate change scenarios suggest that decreased flows in the Blithe and the changes in rainfall and PET would cause a decrease in DO of the system. This is particularly linked to the inflow of the Blithe during the most critical summer months and the likelihood of Blithfield being full by the end of March. The 2080s climate change scenarios (using an unbiased sample) indicate a likely decrease in DO of 27Ml/d and 21Ml/d for the NR and LOS demand saving approach respectively. The respective DO changes for the 2030s were 2Ml/d for NR and 5Ml/d for LOS.

The synthetic drought scenarios show a lesser impact on DO than the 2080s climate change scenarios. The system copes well with the shorter 18-month droughts, giving DO values of 342Ml/d and 332Ml/d for the 200 and 500-year scenarios respectively. However, the system is less resilient against prolonged dry conditions, as the longest 30-month droughts, give DO values of 313Ml/d and 311Ml/d for the 200 and 500-year scenarios respectively. This is caused by Blithfield reservoir being drawn down from full storage earlier in the year either one or two winters before the level 4 failure event.

# 5 References

Mott MacDonald, 2017a. Hydrology update of the Blithe for South Staffordshire Water Plc.

Mott MacDonald, 2017b. Aquator model update for South Staffordshire Water Plc.

Mott MacDonald, 2017c. Synthetic drought flow series for South Staffordshire Water Plc.

Mott MacDonald, 2017d. Climate change flow series for South Staffordshire Water Plc.

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